THE SELECTION OF THE APPROPRIATE EQUIPMENT FOR A PARTICULAR WAREHOUSE SITUATION AND THE SELECTION OF THE APPROPRIATE SITUATIONS FOR A PARTICULAR PIECE OF WAREHOUSE EQUIPMENT

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

by

Anne Frans van der Meer

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in the School of Industrial Engineering

Georgia Institute of Technology

August, 1973

THE SELECTION OF THE APPROPRIATE EQUIPMENT FOR A PARTICULAR WAREHOUSE SITUATION AND THE SELECTION OF THE APPROPRIATE SITUATIONS FOR A PARTICULAR PIECE OF WAREHOUSE EQUIPMENT

Approved:

Chairman

Date approved by Chairman: 8/10/73

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Professor James M. Apple for his valuable guidance and encouragement.

Special thanks are given to Dr. Nelson K. Rogers for his part in bringing about the completion of this work. Thanks are also due to Dr. Kailash M. Bafna for his continuous supportive efforts and to Dr. Robert G. Parker for his service on the Reading Committee.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

ABSTRACT

The purpose of this research was to develop a new methodology of warehouse equipment selection, one which involves determining the degree of mechanization and automation. This was done to overcome the main difficulty in existing selection procedures, the fact that these procedures are unable to cope with selection from a large variety of equipment alternatives.

The method presented is based on the decision tree concept and consists of four decision steps. Every step analyzes the problem in greater detail. In every step, the decisions are made with the help of selection charts. These "determination sheets" enable the analyst to identify arguments in favor of the different alternatives. When the arguments are identified in a systematic way, a choice can be made. Presented are two judgment techniques that can be helpful in making this choice.

The developed method is applied to an equipment selection problem in an existing warehouse situation. This approach leads to the recommendation of a detailed design for a remote hand-controlled item release conveyor system for the item-picking activities.

The developed method, with slight simplification, also can be used to determine the characteristics of any warehouse in which a par-

ticular piece of equipment is applicable. This method is used to determine the characteristics of a situation suitable for automated (computer-controlled) stacker cranes. The final result consists of a list of 48 such characteristics.

CHAPTER I

INTRODUCTION

1-1. Definition of the Problem

The research which was undertaken was directed at the problem of choosing the most appropriate equipment for any warehouse activity or combination of warehouse activities.

1-2. Brief History Leading to the Problem

The main reason for choosing this problem was the researcher's direct involvement with two real-world situations.

1. In the period 1970-1971, he performed a thesis apprenticeship of 12 months with a large company in The Netherlands. The assigned task was to make an optimization study for an automated high-rise warehouse. When he joined the project team, the equipment choice had already been made, but he doubted the validity of the choice. Private attempts to re-evaluate this choice failed because of the complexity of the problem and lack of time.
2. In the period 1971-1972, he worked for the management consulting department of a gramophone record company. His

first assignment was to assist in the concentration of several small warehouses. In this case the new situation was built up as the sum of the past situations, without serious research into new possibilities.

Based on these experiences, he agrees with Apple's statement: "Most materials handling problems are not analyzed--they are solved" (8, 227).[1] As described in Chapter V, Apple gives a general outline for approaching these problems. Equipment selection is an important section of this outline. This research has been conducted on the basis of these fundamentals.

1-3. Objectives, Scope, and Limitations

The objective of this research is to provide the engineer with an effective tool that can be used to select the best warehouse equipment from a large variety of equipment alternatives. This allows the designer of the warehouse to make a wise choice from the different alternatives offered to him by the existing equipment market.

The developed method, after slight simplification, also can be used to determine the characteristics of any warehouse in which a particular piece of equipment is applicable. The method enables the manufacturer to identify the characteristics of the warehouses in which his

---

[1]Numbers in parentheses denote references. The first number is the source of reference and the second is the page number.

particular piece of equipment is applicable. These characteristics could be useful to determine the potential market, to identify individual customers, to identify valid selling arguments, and the like.

This study is limited to warehouses dealing with materials that consist of individual units (packages, etc.). This excludes bulk materials such as sand and tank-type storage activities such as the storage of liquids and gases.

1-4. Review of the Literature

Apple (8, 229) has presented a general procedure for "analyzing and searching for the best solution to a materials handling problem." This procedure consists of the following steps:

Definition:

1. Identify the problem(s)
2. Determine the scope of the problem(s)
3. Establish objective(s)
4. Define the problem(s)

Investigation:

5. Determine what data to collect
6. Establish work plan and schedule
7. Collect data
8. Develop, weigh, and analyze data

Solution:

9. Develop improvements
10. Prepare justification
11. Obtain approvals
12. Revise as necessary

Installation:

13. Work out procedures for implementation
14. Supervise installation
15. Follow up

In applying this procedure to warehouse problems, the analyst is guided into a thorough analysis of the problem instead of drawing a quick conclusion.

Every step of this general procedure has been broken down into several sections. Equipment selection occurs in Step 9.

Apple (8, 368) also presents an "equipment selection procedure" consisting of nine steps. This procedure has been used as a starting point. Similar procedures have been presented by Bazaraa (5) and Rivera (13). Compared to Apple, these authors go into greater detail in carrying out the different steps. In the methods they present, the decisions are made with the help of a chart which enables the engineer to relate relevant factors to equipment alternatives. Bazaraa introduces a selection procedure in two stages: during the first stage the level of mechanization is determined, and in the second stage the specific type of equipment is selected. The disadvantages of these methods are as

follows:

1. The number of factors is limited.
2. Selection in one stage limits the number of alternatives from which a selection can be made. Bazaraa's two-stage selection procedure is an improvement with respect to this point.
3. These methods have not been developed especially for warehouses. A more complicated method has been developed by Frazao (14). The fundamentals of his method are that factors which are relevant to the problem are graded on the basis of several "materials handling principles." However, the validity of his assumptions is debatable.

This research results in a method which does not have these limitations.

CHAPTER II

STORAGE OF MATERIALS

2-1. Materials Storage from a Broad Point of View

Between the point that a raw material is obtained (for example, in a mine) and the point that a finished product is used by the final customer, the material undergoes many transformations. Most of these transformations are related to the physical and chemical characteristics of the material. Three other characteristics, however, are relevant: quantity, place (or location), and time.

With the help of these different material characteristics, different types of transformation processes can be distinguished:

1. Production processes.

   Transformation of physical and/or chemical characteristics (and sometimes a transformation of quantities).

2. Transportation processes.

   Transformation of location.

3. Storage processes.

   Transformation of time.

This is shown in Figure 1.

With the help of the symbols shown in Figure 1, a general scheme

can be drawn to show the chain of transformations for the completion of any product. This is shown in Figure 2.

Process	Material Characteristics to Be Transformed	Symbol
Production	Physical and/or chemical characteristics	○
Transportation	Location	⇨
Storage	Time	▽

Figure 1. The Different Types of Transformation Processes.

With the help of Figure 2, three main reasons for the storage of materials can be identified:

1. A transformation in the physical and chemical characteristics of a specific quantity of material requires a specific amount of time. This can be expressed as transformation capacity. Since successive transformation capacities usually are not equal, material storage takes place as a buffer between two successive capacities.
2. A flow of material usually is not constant. This can be ex-

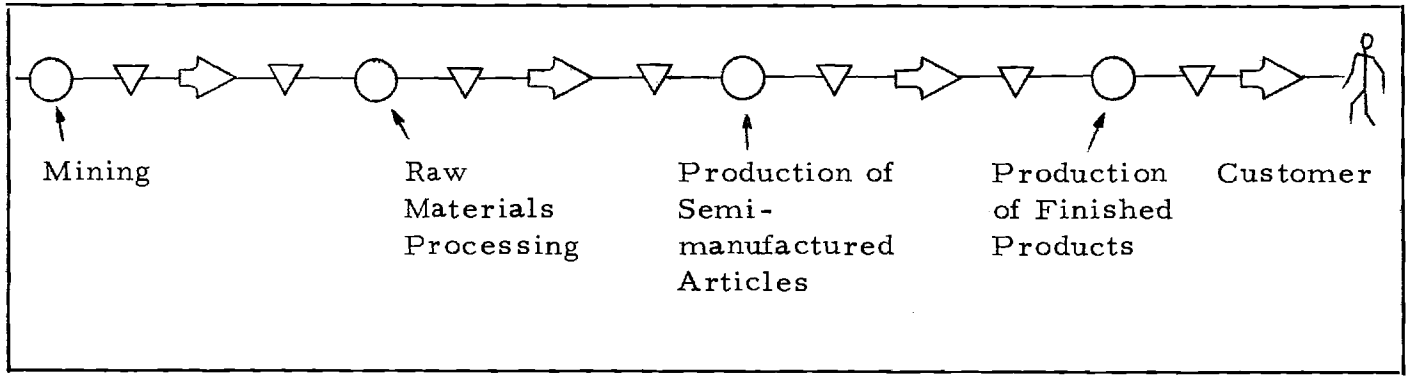


Figure 2. Transformation Processes for the Production of Products.

pressed as the frequency distribution (describing the flow pattern) or a histogram. The frequency distribution of the outgoing flow of a production process is not necessarily the same as the frequency distribution of the incoming flow of the next production process. Hence, in order to adjust the two different flows of materials, material storage takes place.

3. If different production processes take place at different locations, there has to be some kind of transportation in between. Again, the frequency distribution of an outgoing flow of a production process usually is not the same as the incoming flow of a transportation process. And in the same way, the outgoing flow of a transportation process is not adjusted to the incoming flow of the next production process. To adjust two different flows with two different frequency distributions, material storage is necessary.

An example of the incoming flow of a transportation process is the flow of materials that goes from the docks of a warehouse into the delivery trucks. This flow is determined by:

- truck capacity
- truck loading times
- truck arrival schedules

etc.

A facility especially desired for the storage of large quantities of materials is the warehouse.

Several significant conclusions can be drawn from the above discussion.

1. The reasons for material storage are:[1]
   a. Capacity differences, and
   b. Differences in frequency distributions for successive flows of material.
2. Materials storage can be reduced and/or eliminated by:
   a. Adjusting process capacities to frequency distributions.
   b. Adjusting frequency distributions to process capacities.
   c. Adjusting process capacities to process capacities.
   d. Adjusting frequency distributions to frequency distributions.

It is important to look into the possibilities for reducing materials storage before starting to design materials storage facilities.

2-2. Seven Basic Warehouse Types

The relevant literature does not make a distinction between different types of warehouses. For the purpose of equipment selection, how-

---

[1] A third reason for materials storage exists when a predetermined length of storage is required for a particular production process (ripening of wine, etc.).

ever, a useful distinction can be made on the basis of two other general warehouse characteristics: (1) the structure of a warehouse and (2) the type of materials flow.

1. Structure of a warehouse. Within a warehouse, there can be up to four different storage areas:
   - Receiving storage
   - Bulk storage
   - Picking storage
   - Shipping storage

Expressed in "space occupied" and "amount of materials stored," the bulk storage and the picking storage are of the greatest significance. Ignoring the receiving storage area and the shipping storage, two basic structures for a warehouse can be distinguished:

Structure a. There is only one storage area where all the goods are stored. A separate picking storage area does not exist.

Structure b. There are two storage areas:

- A large bulk storage area where the largest quantity of the materials is stored.
- A small picking storage area in which a small amount of all of the warehouse items is stored. This arrangement allows an order to be collected and filled in less time, resulting in improved customer service.

These two warehouse structures can be symbolized as shown in

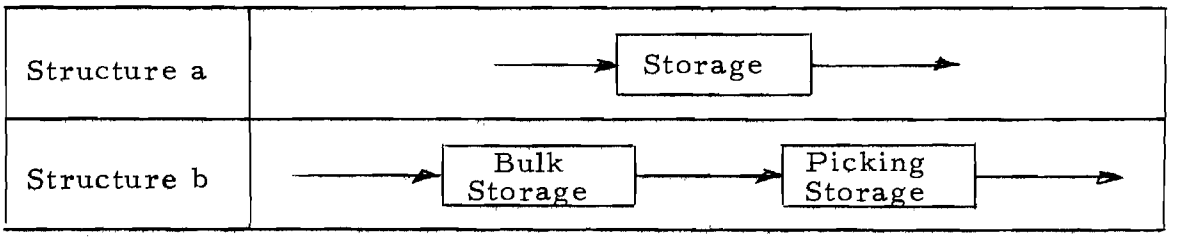


Figure 3. Two Basic Structures for a Warehouse.[1]

Figure 3.

2. Type of materials flow. With respect to mechanization and automation, two types of materials flow can be distinguished:

Type a. The flow of material consists of unit loads.

A unit load can be defined as: a number of items, or bulk material, so arranged or restrained that the mass can be picked up and moved as a single object, too large for manual handling, and which upon being released, will retain its initial arrangement for subsequent movement. It is implied that single objects too large for manual handling also are regarded as unit loads (8, 70).

This study will be limited to unit loads as generally used in a warehouse. Examples are: wooden pallet (sizes from 24 inches x 32 inches to 88 inches x 108 inches; most common size 40 inches x 48

---

[1]The arrows in the figure represent the material flow going into or out of the storage area. The arrows do not necessarily represent incoming and outgoing flows of the warehouse.

inches), skid, sheet pallet (the same sizes as the wooden pallet), and bin (for oblong loads like bars of steel).

Type b. The flow of material does not consist of unit loads but consists of individual handling units (packages, individual items) that usually

- vary in size, shape, weight, etc.
- are smaller than the unit load (small enough for manual handling; see definition of unit load).

These types of handling units are sometimes referred to as "package type units" or "packages," although it can also include individual units such as unpackaged bottles, cheeses, and similar items.

On the basis of these two warehouse structures and these two types of materials flow, 12 different warehouse types can be distinguished. This is shown in Figure 4 (Types A-L).

However, not all of these types are practicable alternatives. It is impossible to take unit loads out of a storage area if unit loads have not been placed into that storage area. In other words, for any square in Figure 4, the outgoing flow cannot be unit loads if the incoming flow is packages. For this reason, Types C, G, H, J, and K can be eliminated (see Figure 4). This results in seven different warehouse types, marked in Figure 4 as Type 1-Type 7.

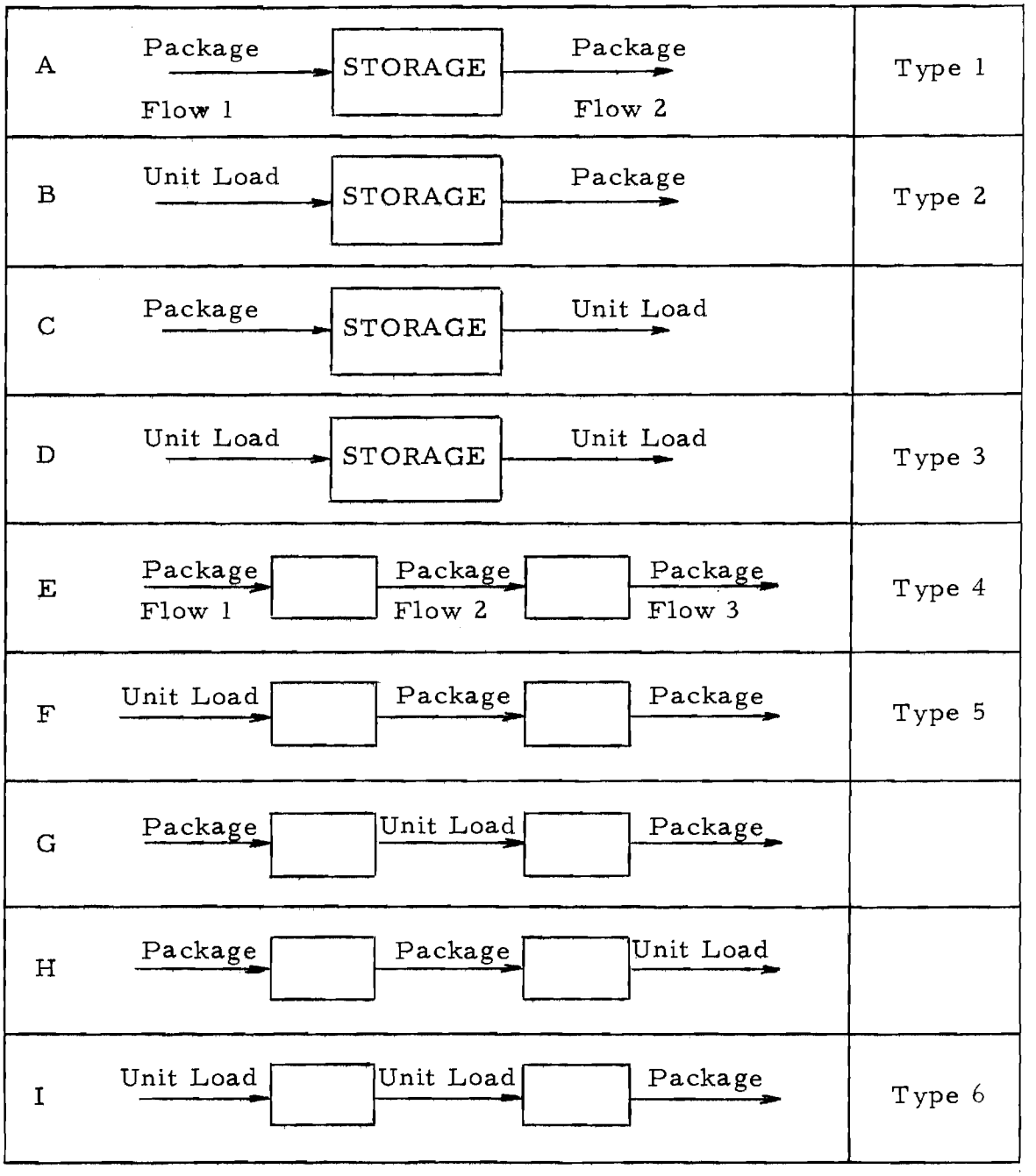


Figure 4. Twelve Basic Warehouse Types.

(page 1 of 2)

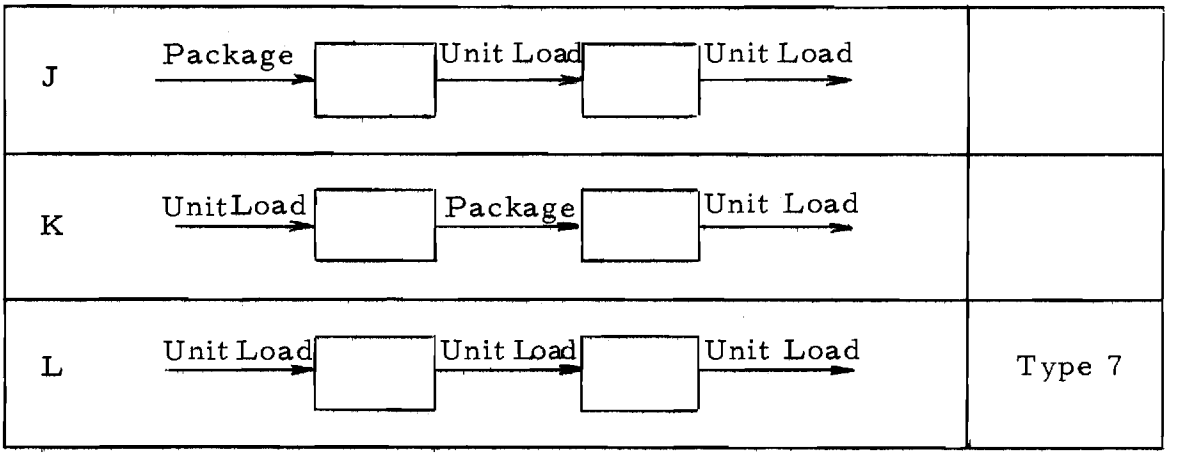


Figure 4. Twelve Basic Warehouse Types.

(page 2 of 2)

CHAPTER III

THE WAREHOUSE AS A SYSTEM

3-1. The Mission, the Requirements, and the Function of a Warehouse System

A warehouse can be regarded as a system. According to De Greene (1), a system can be described by three characteristics:

1. The mission of the system.
2. The requirements of the system.
3. The function of the system.

1. The mission of a warehouse system.

   The mission describes what the system is to do (1, 21). This was defined in Chapter II as the transformation of time for relatively large amounts of goods.

2. The requirements of a warehouse system.

   The requirements of a system can be described as the obligations the system must fulfill to effect the mission (1, 21). In the case of a warehouse system, the requirements describe characteristics of the situation in which the warehouse has to operate, insofar as the functioning of the warehouse in that situation is involved.

   Example: In the case of a distribution warehouse, the ware-

house has to operate as a buffer between the outgoing flow of a production process and a flow that "goes into" the transportation process to wholesaler and/or customers. Requirements for such a warehouse system can be:

a. The characteristics of the material flow coming out of the production process (physical characteristics, quantities, frequency distribution, etc.).

b. The characteristics of the material flow going into the transportation process. Examples are:

   - Transportation schedules
   - Means of transportation
   - Transportation quantities
   - Handling units

c. Situational characteristics, such as:

   - Storage space available
   - Budget
   - Labor market
   - Equipment market
   - Money available for investment

3. The function of a warehouse system.

The function of a warehouse system can be described as the general means or action by which the system fulfills its requirements (1, 21). The most important means by which a warehouse system effects its mission, according to the requirements of the particular situation, is storage. Storage does not include all of the activities, however, that take place in a warehouse. A term that does include all of the activities is "warehousing." Consequently, the function of a warehouse system is warehousing.

3-2. Systems Terminology

In this study a systems terminology as presented in Table 1 will be used.

Table 1. Terminology in a Warehouse System

Physical Elements	Performance
System	Function
Sub-system	Sub-function
Sub-sub-system or Module	Activity
Component	-

a. A warehouse system is built to perform the function "warehousing."

b. A warehouse system can consist of different sub-systems, each performing a sub-function.

   Example: A warehouse system that consists of only one main storage area (no separate order picking area) can be subdivided into six different sub-systems (each performing a sub-function), as shown in Table 2. This example also illustrates that:

c. The sub-systems together make up the total warehouse system; and the sub-functions together make up the total function warehousing.

d. A sub-system also can consist of sub-sub-systems or modules, each performing one (or more) activities.

e. Therefore, a sub-function, as performed by a sub-system, can be broken down into activities.

   Example: The sub-system for receiving (performing the function receiving) can be broken down into three modules (each performing an activity), as shown in Table 3.

Table 2. Six Possible Sub-systems for a Warehouse System

System: Warehouse	Function: Warehousing
Sub-system	Sub-function
1. Sub-system for receiving (facilities, men, equipment)	1. Receiving
2. Sub-system for transporting to storage	2. Transporting to storage
3. Sub-system for storage	3. Storage
4. Sub-system for order collecting	4. Order collecting
5. Sub-system for packing	5. Packing
6. Sub-system for shipping	6. Shipping

Table 3. Three Possible Modules for the Sub-system "Receiving"

Module	Activity
1. Module for unloading	1. Unloading
2. Module for transporting to receiving area	2. Transporting to receiving area
3. Module for identifying, sorting, and inspecting	3. Identifying, sorting, and inspecting

3-3. The Warehouse as a System

3-3-1. The General Warehouse

In order to obtain a general breakdown of a warehouse system into sub-systems and modules, a process chart was made of three different warehouse examples, representing the three most common warehouse types.

Example A. Individual packages are stored on shelves which are seven feet high. The handling is done manually; long moves are made with the help of a hand cart. To obtain a reasonable customer service degree, there are a large bulk storage area and a small picking storage area. This is a warehouse of Type 5 (see page 14).

Example B. Box pallets are stored in high-rise racks. The handling of the pallets to and from the storage area is done with the help of a forklift truck; moves into and out of storage are done with the help of stacker cranes. Some long moves are made with the help of roller conveyors. An order is built up from individual pallet loads; order collecting takes place with the help of an automated flow rack system in a special picking area. This is a warehouse of Type 7 (see page 15).

Example C. Not too different from Example B. However, orders are made up from individual packages (not from pallet loads). Order picking is done in a special picking area with the help of powered, hand-controlled vehicles. The picking itself is by hand. There is no flow rack storage in the picking area. This is a warehouse of Type 6 (see page 14).

The process charts are shown in Appendix A. From these charts a "simplified process chart" for a general warehouse has been developed. This is also shown in Appendix A. The final result is presented in Figure 5.

3-3-2. The Eight Sub-systems of a Warehouse System

From Figure 5 it can be concluded that a warehouse system can be divided into eight sub-systems; each sub-system performs a sub-function. This is shown in Table 4 and illustrated in Figure 6.

3-3-3. The Sub-sub-systems (or Modules) of a Warehouse System

From Table 4 it can be concluded that each sub-system of a general warehouse can be broken down into sub-sub-systems or modules. Each module can perform one or more activities. The modules of the eight different sub-systems of a warehouse are presented in Table 5.

Example: The function receiving can be broken down into three activities:

- Unloading
- Transporting to receiving area
- Identifying, sorting, and inspecting.

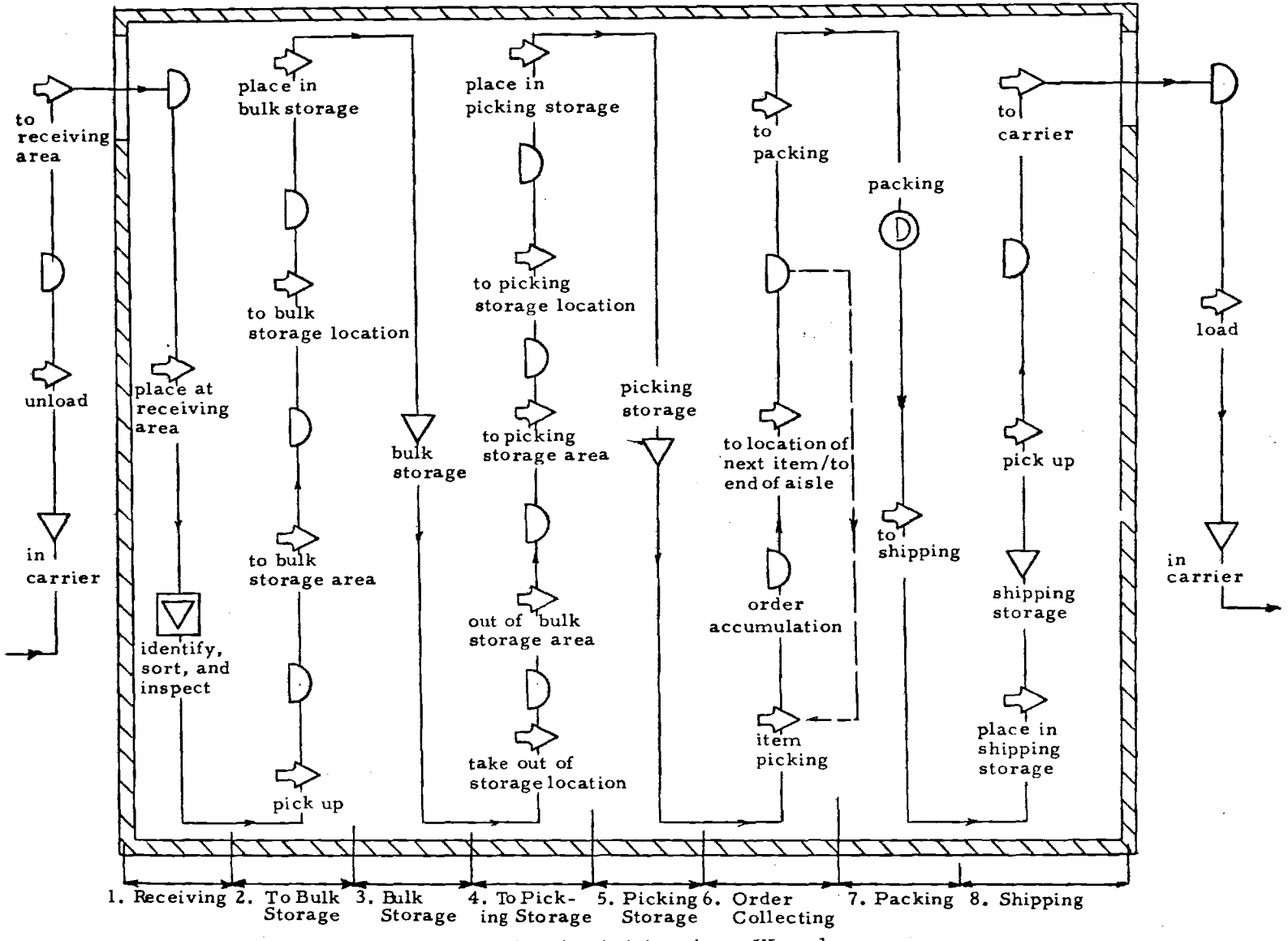


Figure 5. Activities in a Warehouse.

Table 4. The Sub-systems of a Warehouse System

Sub-system[1]	Sub-Function
1. The receiving sub-system	1. Receiving
2. The sub-system for transporting to bulk storage	2. Transporting to bulk storage
3. The sub-system for bulk storage	3. Bulk storage
4. The sub-system for transporting to picking storage	4. Transporting to picking storage
5. The sub-system for picking storage	5. Picking storage
6. The sub-system for order collecting	6. Order collecting[2]
7. The sub-system for packing	7. Packing
8. The sub-system for shipping	8. Shipping

[1]Usually the sub-systems are named after the sub-functions they perform. For example: receiving is used to indicate the receiving sub-system as well as to indicate the receiving sub-function.

[2]Order collecting consists of two parts: item picking and order accumulation.

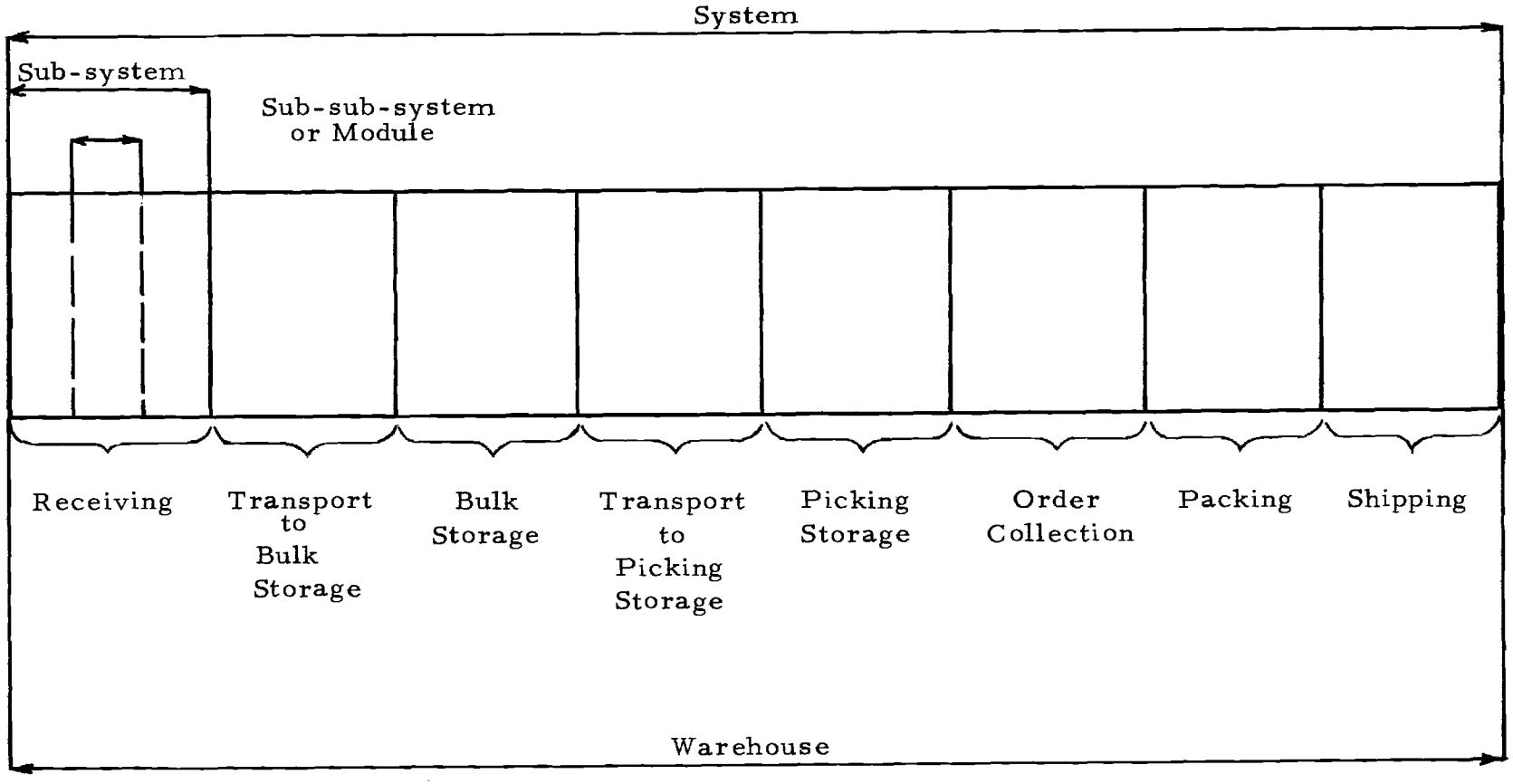


Figure 6. The Subdivision of a Warehouse System.

Similarly, the sub-system for receiving has to be built up from modules performing these three activities. These modules consist mostly of a combination of (a) men, (b) equipment, and (c) facilities.

In systems terminology the problem of equipment selection can be placed in the context of selecting (and/or designing) the right kind of module to perform the required activity. This puts emphasis on the following points:

- Choosing the right kind of module means choosing the right combination of men, equipment, and facilities.
- The design of the module is determined by the particular characteristics of the activity in the particular situation.

Table 5. Subdivision of a Warehouse System

Sub-system	Sub-function	Sub-sub-system or Module	Activity
1. Sub-system for receiving	1. Receiving	1-1. Sub-system for unloading	1-1. Unloading
		1-2. Sub-system for transport to receiving area	1-2. Transport to receiving area
		1-3. Sub-system for identify, sort, inspect, receiving storage	1-3. Identify, sort, inspect,[1] receiving storage
2. Sub-system for transport to bulk storage	2. Transport to bulk storage	2-1. Sub-system for pick up at receiving area	2-1. Pick up at receiving area
		2-2. Sub-system for transport to storage area	2-2. Transport to storage area
		2-3. Sub-system for transport to storage location	2-3. Transport to storage location
		2-4. Sub-system for place in storage	2-4. Place in storage
3. Sub-system for bulk storage	3. Bulk storage	3. Sub-system for bulk storage	3. Bulk storage

Table 5. Subdivision of a Warehouse System (continued)

Sub-system	Sub-function	Sub-sub-system or Module	Activity
4. Sub-system for transport to picking storage	4. Transport to picking storage	4-1. Sub-system for removal from bulk storage	4-1. Removal from bulk storage
		4-2. Sub-system for transport from bulk storage area	4-2. Transport from bulk storage area[2]
		4-3. Sub-system for transport to picking storage area	4-3. Transport to picking storage area[2]
		4-4. Sub-system for transport to picking storage location	4-4. Transport to picking storage[2] location
		4-5. Sub-system for place in picking storage	4-5. Place in picking storage
5. Sub-system for picking storage	5. Picking storage	5. Sub-system for picking storage	5. Picking storage

Table 5. Subdivision of a Warehouse System (continued)

Sub-system	Sub-function	Sub-sub-system or Module	Activity
6. Sub-system for order collecting	6. Order collecting	6-1. Sub-system for item picking	6-1. Item picking[2]
		6-2. Sub-system for: to location of next item/to collecting point	6-2. To location of next item/to collecting point[2]
		6-3. Sub-system for: to packing area	6-3. To packing area
7. Sub-system for packing	7. Packing	7-1. Sub-system for packing	7-1. Packing[3]
		7-2. Sub-system for transport to shipping area	7-2. Transport to shipping area
8. Sub-system for shipping	8. Shipping	8-1. Sub-system for place in shipping storage	8-1. Place in shipping storage
		8-2. Sub-system for shipping storage	8-2. Shipping storage
		8-3. Sub-system for removal from shipping storage	8-3. Removal from shipping storage

Table 5. Subdivision of a Warehouse System (concluded)

Sub-system	Sub-function	Sub-sub-system or Module	Activity
		8-4. Sub-system for transport to truck	8-4. Transport to truck
		8-5. Sub-system for loading	8-5. Loading

[1]Different for different products; not to be specified in more detail.

[2]Usually combined.

[3]Packing is done in different ways for different products. A subdivision into activities for a general warehouse, therefore, is very difficult.

CHAPTER IV

WAREHOUSE EQUIPMENT

4-1. Three Groups of Warehouse Equipment

In Chapter III, the systems approach led to a breakdown of the general warehousing function into several activities (unloading, transport to receiving area, etc.; see Table 5). For the purpose of equipment selection, these activities can be divided into three different groups.

Group 1. Storing activities. Since storing is not an activity in the real sense of the word, a better name would be storage non-activities. Examples are: receiving storage, bulk storage, picking storage, shipping storage.

Group 2. Handling activities. These are the activities that have the main purpose of changing the location of the goods. Examples are: unloading, transport to storage area, place in storage, item picking, etc.

Group 3. Related activities. These are the activities that are characteristic for a particular situation, a particular product, etc. In making a study for a general ware-

house, these activities can only be taken into account in a general way, since they are completely different in different situations. Examples are: identifying, inspecting, packing, sorting, etc.

The existing warehouse equipment can be classified in the same way as the activities:

Group 1. Storage equipment. Examples are: racks, shelves, etc.

Group 2. Handling equipment. Examples are: hand cart, fork-truck, conveyor, stacker crane.

Group 3. Equipment for related activities. Examples are: special inspecting devices, packing machines, strapping machines, sorting conveyors, etc.

It is a sad fact that almost all of the pieces of equipment that can be obtained on the market at the present time can be classified as shown above. This means that very little effort has been made to develop system equipment (i.e., equipment that can perform a number of integrated activities, not necessarily from the same group).

During the last few years, however, an effort in this direction has been made. Manufacturers of warehouse equipment offer warehouse systems instead of pieces of equipment. However, these warehouse systems consist of the same pieces of equipment that mainly have been designed to perform non-integrated activities. In some

cases, slight modifications have been made. There are a few exceptions, for example, flow rack storage. A flow rack is a piece of equipment that can perform both a storing "activity" and some handling activities (moving, release of items).

One of the tasks of an industrial engineer is to provide the equipment designer with the right specifications for the system equipment to be designed.

This study is directed primarily to the selection of handling equipment as offered by the existing equipment market. However, an attempt is made to include those factors of the whole warehouse system that are relevant to the choice of specific types of equipment

4-2. Mechanization and Automation

4-2-1. General Concept

Bazaraa (5) presents a delineation of ten degrees of mechanization of materials handling equipment, as shown in Figure 7. This subdivision has been made on the basis of two characteristics:

1. The source of power of the equipment.

   Bazaraa indicates three possibilities:

   - Manual power
   - Gravity
   - External power

2. The control of the equipment.

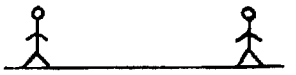
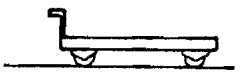
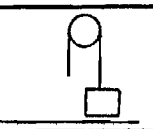
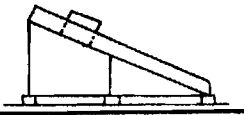
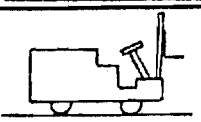
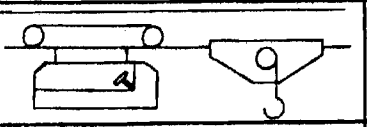
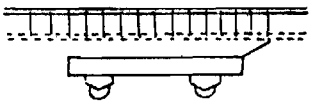
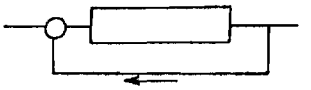
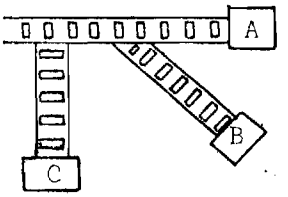
Classification		Level	Description	Examples	Characteristics
Manual Control	Manual Power	1	Hand		Man carries load.
		2	Hand Equipment		Equipment carries load.
		3	Mechanized Hand Equipment		Uses mechanical advantage.
	Gravity	4	Gravity Equipment		Positive control of object.
	External Power	5	Power Equipment, Hand Control		Power does work; man controls power.
		6	Power Equipment, Remote Hand Control		Control remote from load.
Automatic Control	External Power	7	Power Equipment, Program Control		Control according to program.
		8	Power Equipment, Feedback Control		Automatic correction, according to signal.
		9	Adaptive System Equipment		Integrated system of signals and actions.
		10	Fully Automated System Equipment		

Figure 7. A Summary of the Levels of Mechanization of Materials Handling Equipment

Source: Bazaraa, Mokhtar Sadek, "The Determination of the Optimum Level of Mechanization in the Selection of Materials Handling Equipment," Georgia Institute of Technology, 1968.

Here, two possibilities can be distinguished:

- Manual control
- Automatic control.

Apple develops (3) an approach to automation of the complete manufacturing process (which is the total of all of the manufacturing activities). In this approach, automation is related to five different components of the manufacturing process:

1. Make
2. Move
3. Test
4. Control
5. Store.

These components are not specified. A general description could be as follows:

1. Make. This is the actual production operation (drill a hole, saw a board, bend a sheet, assemble a wheel, etc.).
2. Move. This can be anything from moving a bolt from a carton to a workpiece for assembling to transporting semi-manufactured articles from the press shop to the assembly plant.
3. Test. By test is meant the inspection of the material (product). It usually involves a comparison with standard specifications and is mostly done directly after the "make" operation.
4. Control. Two extreme types of control can be distinguished:

a. Control of the overall manufacturing process. This is the process of regulating the transportation flows between different plants, minimizing supplies of materials, avoiding idle time of expensive production equipment, production planning, etc. The latest developments in this area are: computerized management control systems, information systems, inventory control systems, etc.

b. Control of a single manufacturing operation in itself. An example is a man working on a lathe. The man controls the movement of the tools in order to produce a semi-manufactured article.

Between these two extremes, control can have all kinds of scopes, for example, the control of a single plant in a chain of plants and the control of a distribution warehouse.

5. Store. Apple (3) uses "store" to indicate the whole warehousing function, as described in Chapter II. In this study, the term "warehousing" will be used. "Store" is used only to indicate the actual keeping of the materials "on the shelf."

Apple (3) suggests that there are several levels of automation for each of the above five components:

1. For the component "make," 17 levels as developed by Bright (14) can be used. This is shown in Figure 8.
2. For the component "move," the 10 levels as developed by Bazaraa

Initiating Control Source	Type of Machine Response		Power Source	Level Number	LEVEL OF MECHANIZATION
From a variable in the environment	Responds with action	Modifies own action over a wide range of variation	Mechanical (Nonmanual)	17	Anticipates action required and adjusts to provide it.
				16	Corrects performance while operating.
				15	Corrects performance after operating.
		Selects from a limited range of possible prefixed actions		14	Identifies and selects appropriate set of actions.
				13	Segregates or rejects according to measurement.
				12	Changes speed, position, direction according to measurement signal.
	Responds with signal			11	Records performance.
				10	Signals preselected values of measurement. (Includes error detection)
				9	Measures characteristic of work.
From a control mechanism that directs a predetermined pattern of action	Fixed within the machine			8	Actuated by introduction of work piece or material.
				7	Power Tool System, Remote Controlled
				6	Power Tool, Program Control (sequence of fixed functions).
				5	Power Tool, Fixed Cycle (single function).
From man	Variable			4	Power Tool, Hand Control.
				3	Powered Hand Tool.
			Manual	2	Hand Tool.
				1	Hand.

Figure 8. Seventeen Levels of Mechanization and Their Relationship to Power and Control Sources.

Source: Bright, James R., Automation and Management, The Plimpton Press, Norwood, Massachusetts, 1958.

(see Figure 7) can be used.

3. For the component "test," Apple suggests a list of eight levels, as shown in Figure 9.
4. For the component "control," Apple suggests a subdivision of six steps, as shown in Figure 10.
5. For the component "store," the same 10 levels as used for "move" are suggested.

4-2-2. Automation of the Warehouse Function

The automation concept of the manufacturing process can be applied also to the warehouse process. In this case, automation can be related to four different components:

1. Store (storage activities)
2. Move (handling activities)
3. Related activities
4. Control.

Storage activities, handling activities, and related activities were described earlier in this chapter.

Within a warehouse different kinds of control take place. Two extremes are:

a. Control with a large scope. This is concerned with the total inventory, the customer service degree, the total operating costs, total efficiency, etc.
b. Control with a small scope. This is the control on the level of

1. Visual inspection (mental evaluation of characteristics)
2. Hand gauging (quantitative value of characteristics)
3. Mechanical or electrical gauging (additional accuracy)
4. Measuring and sorting (separates items by size)
5. Signaling attention (signals unacceptable deviations)
6. Recording measurements (displays sizes)
7. Correcting variations (adjusts to eliminate deviations)
8. Predicting and correcting (anticipates deviation and adjusts to prevent it)

Figure 9. Levels of Mechanization for Component TEST

Source: Apple, James M., "The Systems Approach to Material Handling in Automation," Technical Paper MS 69-531, American Society for Tool and Manufacturing Engineers, 20501 Ford Road, Dearborn, Michigan 48128.

1. Signal (for attention)
2. Record performance (for examination and decision)
3. Identify deviation (compare with standard)
4. Interpret consequences (calculate and translate significance of deviation)
5. Initiate appropriate action (correct performance)
6. Anticipate performance and adjust to prevent deviation

Figure 10. Subdivision of Component CONTROL

Source: Apple, James M., "The Systems Approach to Material Handling in Automation," Technical Paper MS 69-531, American Society for Tool and Manufacturing Engineers, 20501 Ford Road, Dearborn, Michigan 48128.

"picking up an item from a hand cart and placing it in the right storage location."

(In equipment selection "control" is generally used to indicate the direct control of the activities. If the activity is performed with the help of equipment, one speaks about the control of the equipment.)

For each of these four components, it is suggested that there are several levels of automation:

For the component "store," Apple (3) suggested 10 levels as developed by Bazaraa. However, since in this study "store" is not used to describe the whole warehousing function but only the function of storage non-activity, this is not applicable. It is impossible to distinguish levels of automation for a non-activity. Activities can be automated; non-activities cannot be automated.

For the component "move," the 10 levels of Bazaraa can be used.

For the component "particular activities," it is very difficult to present a list of levels of automation, since these activities are completely different in different situations.

For the component "control," six levels as presented by Apple can be used. However, for the purpose of equipment selection, control is generally used to indicate the direct control of the activity performed by the equipment. This parameter was one of the two basic characteristics on which Bazaraa based his list of 10 degrees of mechanization for materials handling equipment. So in the case of the

selection of handling equipment, choosing the level of mechanization for the component "move" automatically means a choice of the level of mechanization for the component (direct) "control."

4-2-3. Conclusion

For the purpose of equipment selection, the mechanization and automation of the warehouse function can be approached by concentrating on the level of mechanization for the components "move" and "control" of the total warehouse function. In this approach the particular activities are minimized in the analysis. The scale of 10 levels of mechanization, as developed by Bazaraa and shown in Figure 7, can be used to indicate both the levels for "move" and (direct) "control" (of the move) at the same time.

As suggested by Pascual (12), this scale of 10 levels of mechanization can be simplified by distinguishing three classes of mechanization:

1. Manual (Levels 1-4)
2. Mechanized (Levels 5-6)
3. Automated (Levels 7-10)

This simplification can be helpful in rough orientation studies.

4-3. Alternative Possibilities for Handling Equipment in a Warehouse

Apple (7&8) presents three basic types of handling equipment:

1. Conveyors
2. Cranes and hoists
3. Industrial vehicles.

Bazaraa (5, 45) presents the possible levels of mechanization for 29 different equipment possibilities, according to his scale of 10 levels. This is shown in Figures 11-13.

A detailed survey of existing handling equipment also can be found in the Materials Handling Handbook (16).

To obtain an overview of the alternative equipment possibilities for handling goods in a warehouse, the following list was compiled from the above three sources:

1. Conveyors
   a. Gravity conveyors (chute, wheel conveyor, roller conveyor)
   b. Roller conveyors (powered)
   c. Belt conveyors
   d. Chain conveyors (rolling chain conveyors, sliding chain conveyors)
   e. Chain conveyors with special construction (apron conveyors, arm conveyors, pusher bar conveyors, slat conveyors, suspended tray conveyors, flight conveyors, drag chain conveyors)
   f. Trolley conveyors
   g. Power and free conveyors
   h. Monorail conveyors (overhead)

	Equipment	Levels of Mechanization									
		1	2	3	4	5	6	7	8	9	10
1	Apron Conveyor										
2	Arm Conveyor										
3	Belt Conveyor										
4	Bucket Elevator										
5	Chute										
6	Drag Chain Conveyor										
7	Flight Conveyor										
8	Pneumatic Conveyor										
9	Power and Free Conveyor										
10	Roller Conveyor										
11	Rolling Chain Conveyor										
12	Screw Conveyor										
13	Slat Conveyor										
14	Sliding Chain Conveyor										
15	Suspended Tray Conveyor										
16	Tow Conveyor										
17	Trolley Conveyor										
18	Cross Bar Conveyor										
19	Oscillating Conveyor										

Figure 11. Levels of Mechanization Corresponding to Different Types of Conveyors.

Source: Bazaraa, Mokhtar Sadek, "The Determination of the Optimum Level of Mechanization in the Selection of Materials Handling Equipment," Georgia Institute of Technology, 1968.

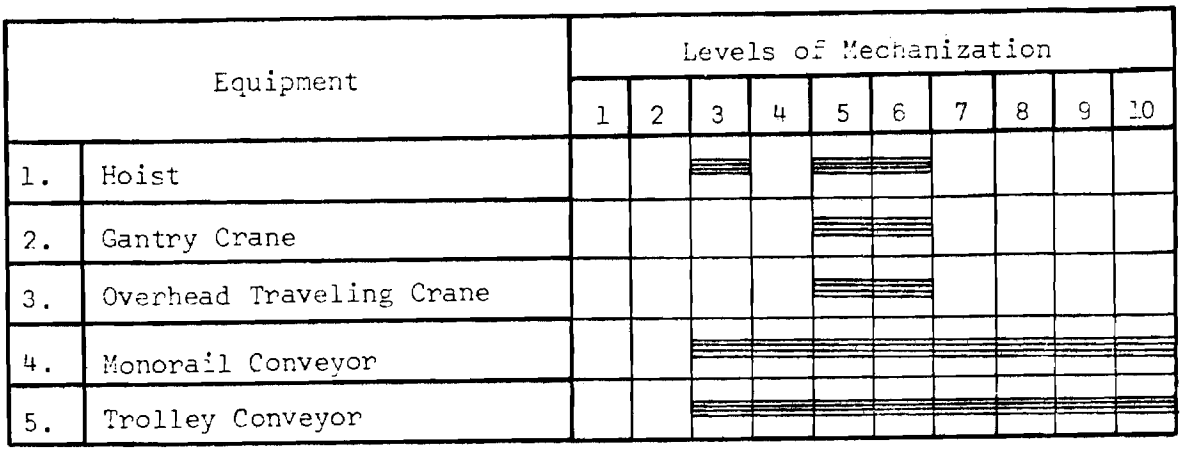


Figure 12. Levels of Mechanization Corresponding to Different Types of Overhead Equipment.

Source: Bazaraa, Mokhtar Sadek, "The Determination of the Optimum Level of Mechanization in the Selection of Materials Handling Equipment," Georgia Institute of Technology, 1968.

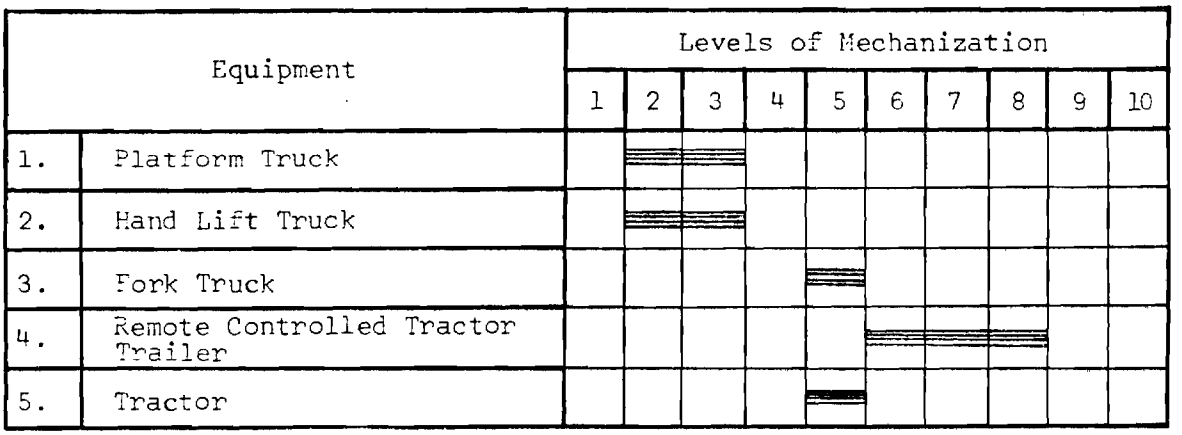


Figure 13. Levels of Mechanization Corresponding to Different Types of Industrial Vehicles.

Source: Bazaraa, Mokhtar Sadek, "The Determination of the Optimum Level of Mechanization in the Selection of Materials Handling Equipment," Georgia Institute of Technology, 1968.

i. Tow conveyors (under floor or overhead)

j. Pneumatic conveyors

k. Oscillating conveyors

2. Cranes and hoists

a. Overhead cranes (jib crane, bridge crane, gantry crane)

b. Stacker crane (order picking crane)

c. Hoist

3. Industrial vehicles

a. Platform truck (dolly, two- or four-wheel hand truck)

b. Hand lift truck

c. Crane truck

d. Forklift truck, narrow aisles truck, reach truck, side loader

e. Order picking truck

f. Industrial tractor, with trailers, as in "a."

These different specific types of equipment can be regarded as competitive alternatives for application in a warehouse.

4-4. The Equipment Alternatives for the Different Specific Warehouse Activities

In Chapter III, the warehousing function was subdivided into several activities. These activities were divided into three groups: storage activities, handling activities, and particular activities. In Section 4-2, it was concluded that for the purpose of equipment selection,

the mechanization and automation of the warehouse function can be approached by concentrating on two components: move and (direct) control. It was also concluded that a scale of 10 levels can be used to indicate both the levels of mechanization of move and (direct) control.

To obtain an overview of the alternative equipment possibilities for application in a warehouse, the most common specific types of handling equipment were selected in Section 4-3.

After the above two steps were taken, charts were developed that show for any handling activity in a warehouse the equipment alternatives ranked in accordance with their level(s) of mechanization/automation. These "Overviews of Equipment Alternatives" are listed in Appendix B.

An example is shown in Figure 14. In this example, the subfunction receiving consists of three handling activities: unloading, transport to receiving area, and place at receiving area. (Place at receiving area is part of the particular activities: identifying, sorting, and inspecting; see Chapter III).

For the handling activity "unloading," the following equipment alternatives with the following levels of mechanization/automation can be determined:

Level 1	Hand
Level 2	Hand lift truck
Level 3	Hoist
	Hand lift truck

Level 5 Overhead crane (different types)

Fork truck

Hoist

Level 6 Overhead crane (different types)

Hoist.

In this way, and with the help of the charts of Appendix B, the equipment alternatives can be identified for any handling activity in a warehouse.

Sub-function: 1. Receiving

Level of Mechanization	Unload	To Receiving Area	Place at Receiving Area
Hand 1	Hand	Hand (Carrying)	Hand
Hand Equipment 2	Hand Lift Truck	Platform Truck	
Mechanized Hand Equipment 3	Hoist Hand Lift Truck	Platform Truck	Hoist
Gravity Equipment 4		Gravity Conveyor Chute	
Power Equipment Hand Control 5	Overhead Crane Fork Truck/Crane Truck/Reach Truck Hoist	Conveyors, Different Types Tractor	
Power Equipment Remote Hand Control 6	Overhead Crane Hoist	Driverless Tractor Conveyors, Different Types	
Power Equipment Program Control 7		Conveyors, Different Types Driverless Tractor	
Power Equipment Feedback Control 8		Conveyors, Different Types Driverless Tractor	
Adaptive System Equipment 9		Conveyor: Some Types: Monorail, Trolley, Tow Conveyor	
Fully Automated System Equipment 10		Conveyors: Monorail, Trolley, and Tow Conveyor	

Figure 14. Overview of Equipment Alternatives.

CHAPTER V

THE SELECTION OF WAREHOUSE EQUIPMENT

5-1. Introduction

In real-world situations, the selection of warehouse equipment is very often done in the following way:

1. Determine one or more equipment alternatives.
2. Compare the alternatives with each other and/or with the existing situation. This is generally done by calculating the direct economic consequences of each alternative.
3. Select the "best" alternative on the basis of these calculations.

Step 2 may involve a considerable amount of work (detailed design, cost calculations, etc.). If the problem were approached from a broader point of view to include the introduction of more equipment alternatives, use of the above procedure for selection would result in an enormous amount of design and calculation work in Step 2. The following illustration demonstrates this problem.

A machine factory uses a manually operated warehouse for steel bars of various shapes and cross sections and sheet metal. Top management makes the decision that a new warehouse has to be built and suggests that an automated stacker crane system be considered because

a Swedish competitor uses such a system. A study is made including a rough design of the new warehouse (height, number of stacker cranes, aisle length, etc.). The study takes about one year (10).

Once the cost data for the new design are available, the new facility is compared with the existing situation, and a final decision is made to go ahead with the new warehouse or to drop the idea. In the selection process, barely any consideration has been given to other equipment possibilities. However, in addition to other alternatives having the same degree of automation (such as flow rack conveyor systems and driverless tractor train circuits), there are many alternatives with a degree of automation which is lower than the stacker crane system but higher than the existing situation (such as side loaders, reach trucks, fork trucks with clamps for bars and magnetic or suction devices for sheet material, etc.). Considering these alternatives, however, means the introduction of a multitude of design work and an unacceptable delay of the final decision. As a result, all of the other alternatives are not taken into account, and the chances are fairly good that a non-optimal selection will be made even if the stacker crane system turns out to be more economical than the existing situation.

From the example cited, it is clear that another method is needed to select equipment from a large variety of alternatives. Apple (8) presents a procedure for this purpose. A basic characteristic in his approach is that a decision is not only made on the basis of direct eco-

nomic consequences but also on the basis of more qualitative factors that are relevant to the problem. According to him, the selection should be made in two stages: (a) a pre-selection stage in which (i) the degree of mechanization is determined, (ii) the type of equipment is selected (conveyor, industrial truck, or crane and hoist), and (iii) the specific type of equipment is selected (apron conveyor, side loader, etc.); and (b) a final selection stage in which (i) the cost calculations are made for the equipment alternatives selected, and (ii) the final equipment is selected.

More specific studies in varying depths (especially for the pre-selection stage) have been made by Bazaraa (5), Pascual (12), and Rivera (13).

In this chapter a new pre-selection stage is developed for the selection of warehouse equipment. With this new pre-selection stage, the total procedure for the selection of warehouse equipment consists of the following steps:

1. Pre-selection:
    a. Identify all of the relevant factors.
    b. Select the appropriate warehouse type.
    c. Select the appropriate class of mechanization.
    d. Select the appropriate level of mechanization.
    e. Select the type(s) of equipment.
2. Final Selection:

a. Evaluate the alternatives.

b. Select the specific equipment.

c. Prepare the specifications.

d. Procure the equipment.

A graphic representation of this new pre-selection stage is shown in Figure 15.

The steps of the new pre-selection stage are described on the following pages, and the methods for implementing them also are presented. For each step of the pre-selection stage, charts have been developed that enable the analyst to identify qualitative and quantitative arguments in favor of the various alternatives.

5-2. Procedure for the Pre-selection of Warehouse Equipment

5-2-1. Step 1. Identify All of the Relevant Factors

The first step in the procedure is to identify all of the factors that are relevant to the problem. A method of identifying the relevant factors for any activity in operations and facilities systems design is presented by van der Meer (2). The method consists of a selection procedure by which relevant factors can be identified from a master list of over 500 factors. With the help of this method, the factors relevant to the selection of warehouse equipment have been identified. This identification process is described in Appendix C, and the results are shown on the following pages.

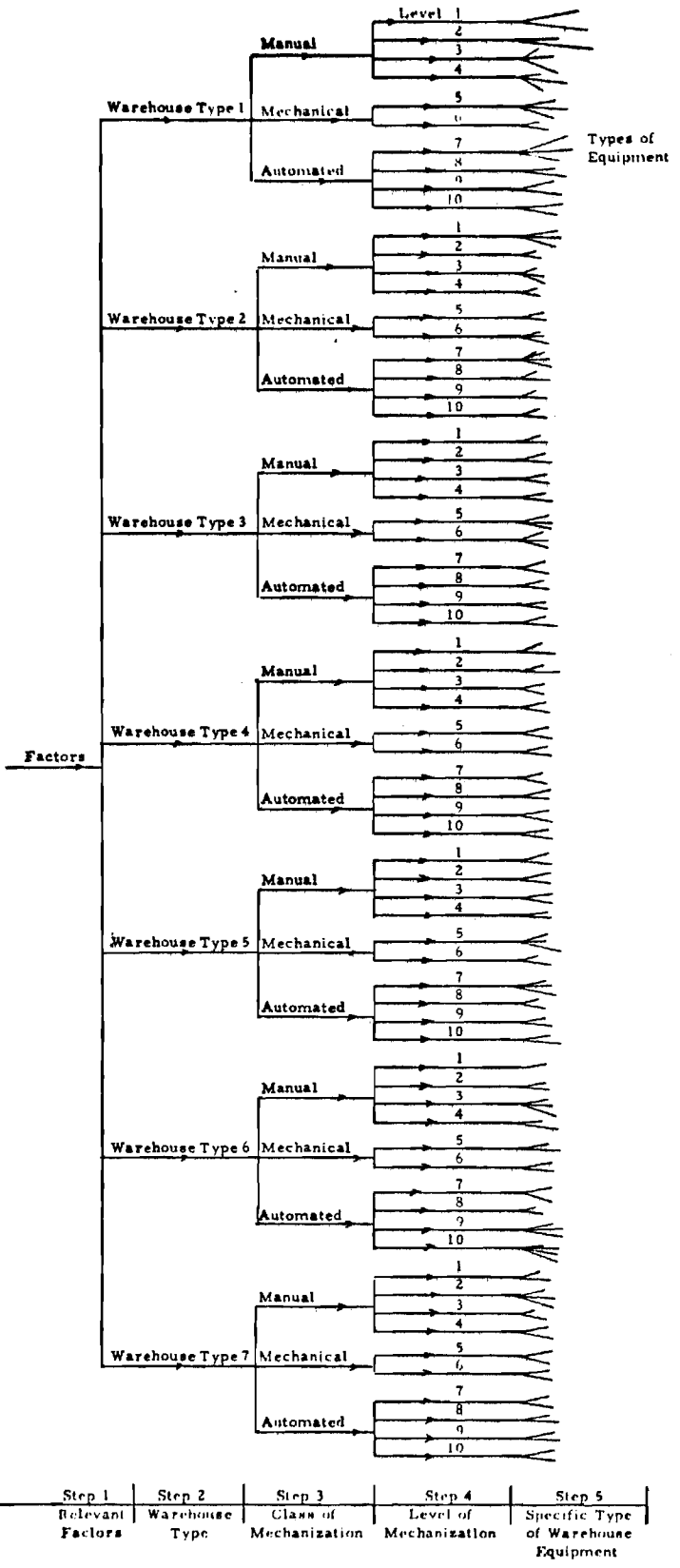


Figure 15. Graphic Presentation of the New Pre-selection Method

List of Selected Factors Relevant to Selection of Warehouse Equipment:

1. Type of material. For practical purposes, this study is limited to materials consisting of units (package type units or unit loads).
2. Shape/form of handling unit. This indicates the geometric shape of the unit being handled. For the purpose of this study, a distinction is made between a regular shape and an irregular shape.
3. Dimensions of the handling unit. Usually, the length, the width, and the height of a handling unit. For the purpose of the approach, the dimensions will be viewed as:
    1. small
    2. medium
    3. large.

    These classifications are not distinctly separated. What one person might consider as small may be considered as medium by somebody else. However, it is very difficult to establish quantitative limits because these limits vary from one industry to another, from one country to another, and even from one situation to another. As a result of this difficulty, this parameter can be used only as a qualitative factor.
4. Uniformity of the handling units. By uniformity is meant the uniformity of the sizes of the different units being handled.
5. Total average quantity. By this is meant the total throughput of the

warehouse per unit of time. As explained under Factor 3, it is very difficult to establish distinctive limits. For the purpose of this study, the following subdivision has been made:

1. low
2. medium
3. high.

6. Number of orders per day. A distinction is made between:
   1. low: 1-100 orders per day
   2. medium: 100-300 orders per day
   3. high: over 300 orders per day.

   Note: The quantitative limits have been adopted from Pascual (12). In making an investigation in a particular situation, the analyst should check whether these limits are acceptable for this situation.

7. Quantity per delivery (from supplier) per item. A distinction is made between "less than one unit load" and "more than one unit load," to find an indication whether the incoming materials flow can be built up from unit loads.

8. Quantity per order per item. A distinction is made between "less than one unit load" and "more than one unit load," to find an indication whether the outgoing orders can be built up from unit loads.

9. Peak quantities. Peak quantities are usually expressed as a relative quantity with respect to the average throughput. For the pur-

pose of this study, the following subdivision has been made:

1. low: peak quantities are less than twice the average quantity
2. high: peak quantities are more than twice the average quantity.

10. External factors. In particular situations there can be particular reasons that favor or disfavor a certain alternative. Local conditions, suppliers' and customers' desires, wishes of the sales department with respect to packaging, etc., fall into this category.

11. Stock quantities per item. If large storage volumes are necessary to store an item, travel distances in the bulk storage become large and a separate picking storage area might be worthwhile. As described under Factor 3, it is very difficult to establish distinctive limits. For the purpose of this study, the following subdivision has been made:

    1. low
    2. medium
    3. high.

12. Required order delivery time (customer service degree). For the purpose of this study, a distinction useful in this general method could be:

    1. short: less than one day
    2. long: more than one day.

As mentioned in 6, the analyst should not hesitate to change this quantitative limit if this is more applicable in his particular situation.

13. Competitors warehouse. If the situation of the competition is comparable with the studied situation, the way the competitors operate might give indications with respect to the various alternatives.

14. Weight of handling unit. This is the weight of the unit being handled. The following subdivision has been made:

    1. under 50 pounds
    2. 50-1,000 pounds
    3. 1,000-10,000 pounds
    4. over 10,000 pounds.

15. Area involved. This expresses the whole area in square feet in which the activity can take place. For instance, item picking can take place anywhere in the picking storage area. It is very difficult to distinguish distinctive limits. For the purpose of this study, the following subdivision has been made:

    1. small
    2. medium
    3. large.

16. Distance of the move. This is the actual distance in feet that the material has been displaced during the handling activity. The following distinction has been made:

1. short: under 100 feet
2. medium: 100-300 feet
3. long: over 300 feet.

17. Frequency distribution. In materials handling, this factor is used to describe the flow pattern with respect to time. The usual way to present this is by way of a histogram. On the horizontal axis the time is plotted (for example, 8 hours a day), and on the vertical axis the flow is plotted (for example, the quantity in every hour). In this way the frequency of the arrival of handling units is pictured as a function of time. The following distinction has been made:
    1. No variability. The frequency of arrivals is constant with respect to time.
    2. Low variability. The frequency of arrivals varies as a function of time.
    3. High variability. The frequency of arrivals varies very much as a function of time.
18. Likelihood of change of product or product mix. Because of the high cost of automated equipment, it is not very practical to introduce a high degree of automation if the product mix is likely to change within a few years. The following subdivision has been made:
    1. Stable. No change within five years.
    2. The product is likely to change between one and five years from now.

3. The product is likely to change within one year.

19. Present information system/record keeping system. Automation mostly requires an information system and a record keeping system that has been computerized, at least up to a certain degree.

20. Total storage space. In general, the total space in cubic feet used for storage can give an indication about automation. The following subdivision has been made:

    1. small
    2. medium
    3. large.

21. Number of line items stored. This is the total number of different item types that is stored. As Factor 20, this can give only a general indication. The following subdivision has been made:

    1. under 200 line items
    2. 200-3,000 line items
    3. 3,000-10,000 line items
    4. over 10,000 line items.

22. Future expansions. Plans for future expansions can be an extra stimulation for introducing mechanization/automation.

23. General economic conditions. This factor refers to the whole economy. The purpose is to take into consideration economic depressions, recessions, etc. The following subdivision has been made:

    1. Favorable. General growth figures are increasing.

2. Unfavorable. General growth figures are decreasing.

24. Growth potential and trends. This factor refers to the particular industry, the particular company, etc. The following subdivision has been made:

    1. Favorable. The growth is larger than the average economic growth.
    2. Constant. The growth is equal to the average growth.
    3. Unfavorable. The growth is smaller than the average economic growth.

25. Wages. Existing wages required by labor unions or by governmental legislation (minimum wages) influence the decisions on automation. The following distinction has been made:

    1. low
    2. medium
    3. high.

26. Employees attitude. To make a new system work, a negative attitude of the employees is intolerable. Especially in the case of the introduction of automation in an existing situation, the system has to be changed according to specific employees' wishes, and employees have to be introduced to the new system in an honest and clear way. It is important that the employees are consulted on the design of the new system from the very beginning of the design process.

27. Management attitude. It is not very practical to perform detailed

studies for introducing advanced equipment if management is not interested.

28. Comfort and fatigue. In general, the introduction of mechanization and automation results in more comfort and less fatigue for the employees involved.

29. Monotony of job. In some cases introduction of automation can also mean the introduction of monotonous jobs. An example is the job of a man picking items while sitting in an outside controlled order-picking vehicle.

30. Financial policy. If the financial situation of the firm and/or the financial policy of the management is such that not many funds are available for investment, it is difficult to have an automation proposal approved and carried out.

31. Labor market. If it is difficult to obtain a certain type of labor regardless of what the wages are, mechanization and automation are stimulated highly.

32. Fragility of material. In general, the applicability of remote hand controlled equipment is limited for fragile materials unless special measures have been taken.

33. Seasonality. Seasonality is the variation in quantities during the different seasons. This is a typical characteristic of the product. There might be some overlap with Factor 7. The following subdivision has been made:

1. Constant quantities. No seasonal variations.
2. Variable quantities. Some seasonal variations.
3. Highly variable quantities. High seasonal variations.

34. Complexity of activity (activities). In some cases, remote hand control is very difficult if the activity is very complex. It may require special equipment that cannot be bought on the market; it may even cause mechanical problems that cannot be solved. The following distinction has been made:
    1. Simple activities
    2. Complex activities
    3. Very complex activities.
35. Path. Some types of control (program controlled equipment) are limited in the complexity of the path that can be performed. The following subdivision has been made:
    1. Simple path
    2. Compound path
    3. Complex path.
36. Number of origins and number of destinations. Especially gravity equipment (Level 4) is not very applicable to an activity in which a move can take place between a large number of origins and a large number of destinations. A distinction is made between "one or a few" and "many."
37. Cross traffic. If the route of the move in the situation is such that

cross traffic has to take place, some types of equipment (conveyors and gravity equipment) are limited in their applicability.

38. Aisle width. The width of the aisle is an important factor with respect to building construction (columns, walls) and utilization of storage space. The following distinction has been made:

    1. narrow: under 6 feet
    2. wide: over 6 feet.

39. Ceiling height/Clear height. Important equipment alternatives (Level 6: middle size and large cranes) cannot be used with low ceiling heights. The following subdivision can be made:

    1. low: under 12 feet
    2. medium: 12-20 feet
    3. high: over 20 feet.

40. Column spacing. This is the distance between the columns. Columns can be important obstacles for large pieces of equipment. The following distinction can be made:

    1. small: under 15 feet
    2. medium: 15-30 feet
    3. large: over 30 feet.

41. Column load capacity. Column load capacities can limit the applicability of pieces of equipment that are supported by the columns (Level 6: overhead cranes). The following distinction has been made:

1. low: under 2,000 pounds
2. medium: 2,000-10,000 pounds
3. high: over 10,000 pounds.

42. Floor running surface. Most equipment types of Level 5 (riding equipment) require a smooth running surface.

43. Skill required. Introduction of mechanization and automation can bring important changes with respect to the required skills of the employees. The following subdivision can be made:

    1. low skills: grade school education or less
    2. medium skills: specialized education
    3. high skills: college level.

44. Noise produced. Some types of equipment (Level 6: forklift truck driven by a gasoline engine) can produce noise that might be unacceptable in specific cases. The following distinction has been made:

    1. low noise level
    2. high noise level.

45. Levels of route. This factor refers to the vertical distance from the floor. A move can include one, a few (two to five), or several (over five) levels.

46. Sequence of moves. Moves of different items and different moves of one item can have a fixed or a variable sequence.

47. Dimensions of building. The application of large pieces of equipment

can be restricted by the dimensions of the building. A distinction is made between:

1. small
2. medium
3. large.

48. Shape of building. The application of certain pieces of equipment can be favored or disfavored by the shape of the building (an example is a tow line conveyor in a rectangular building). The following distinction has been made:

    1. square
    2. rectangular
    3. other.

49. Number of floors. This refers to the number of floors of the building in which the equipment operates, as far as the activities performed with the help of the equipment are involved. The following distinction has been made:

    1. one
    2. more than one.

50. Space available for equipment. In existing situations the introduction of new and larger equipment can be restricted because of the space available for the equipment. The following distinction has been made:

    1. small

2. medium

3. large.

51. Construction of building. If the equipment must be supported by the building construction (framework supporting a crane, but also floor construction supporting a heavy vehicle), this construction becomes important. Also, if a change has to be made in an existing building, the possibilities for changing depend on the construction. A distinction has been made between:

    1. steel construction

    2. concrete construction

    3. other.

52. Legal requirements. The introduction of a new piece of equipment may include the introduction of special measures with respect to operation, safety of personnel, insurance, maintenance, environment, etc. The following distinction has been made:

    1. special measures necessary

    2. no problems.

53. Number of aisles. With respect to warehouse equipment, this factor gives an indication about the applicability of different alternatives. For example, conveyors are not very useful in a situation with many aisles. On the other hand, stacker cranes are more effective in a situation with relatively few aisles. The following distinction has been made:

1. a few
2. many
3. to be determined.

54. Location of aisles. This factor can give an indication whether an existing storage situation can be changed in accordance with the requirements of new equipment alternatives. A distinction is made between:
    1. a fixed location
    2. a location that can be determined.

55. Stacking height. The applicability of important groups of warehouse equipment (fork trucks, reach trucks, side loaders, stacker cranes, etc.) is determined by the required stacking height. A subdivision has been made between:
    1. low: under 12 feet
    2. medium: 12-20 feet
    3. large: over 20 feet.

56. Floor weight limits. One of the factors that can limit the stacking height is the maximum floor weight. The applicability of heavy riding equipment can also be restricted. A distinction has been made between:
    1. low: under 250 pounds per square inch
    2. medium: 250-1,000 pounds per square inch
    3. high: over 1,000 pounds per square inch.

57. Ramps. Existing ramps have to be considered in the choice of important groups of warehouse equipment (loading and unloading equipment).

58. Sales unit of product. In selecting new warehouse equipment, it is wise to consider the existing or future sales unit(s) of the product in order to compare this with the existing handling unit. The following distinction can be made:

    1. Sales unit can be used as handling unit.
    2. Sales unit cannot be used as handling unit.

59. Package characteristics. As with the previous factor, existing package types can indicate the applicability of certain equipment alternatives. Packages may be handling units that can be moved very easily by a specific type of equipment (flow rack systems), or packages may be very suitable for building up unit loads (pallet loads or soap powder boxes). The following distinction has been made:

    1. Package can be handling unit.
    2. Packages can be arranged into unit load.
    3. Package is difficult to handle.

60. Shipping and receiving schedules. This factor can be important with respect to the utilization of equipment capacities.

61. Carrier characteristics. Equipment in the receiving and shipping area has to be suitable for the loading and unloading of the arriving carriers.

62. Inventory policy. This factor has an indirect influence on the warehouse system since it determines the operation of the system as a whole. Changes in policy can mean a change of the whole warehousing function. Before choosing a type of equipment (especially when a large investment is involved), review of inventory policy can be very useful.

63. Motivation and satisfaction. For different equipment alternatives, this factor can vary highly. A distinction has been made between:

    1. low motivation and satisfaction
    2. normal motivation and satisfaction
    3. high motivation and satisfaction.

64. Heat produced. Some types of equipment could produce heat that might be unacceptable. A distinction has been made between:

    1. unacceptable temperature
    2. acceptable temperature.

65. Injuries. Some equipment types are more dangerous than others. A distinction has been made between:

    1. safe
    2. dangerous.

66. Union attitude. The attitude of labor unions is important with respect to automation, lay off of personnel, etc. It also has an influence on employees' attitude and management's attitude. A distinction has been made between:

1. Positive attitude
2. Indifferent attitude
3. Negative attitude.

67. Labor legislation. Automation becomes more attractive if labor costs are rising because of legislation concerning minimum wages, insurances (illness, injuries, retirements), working times, lay off procedures, and other issues. The following distinction has been made:
    1. Many obligations and/or restrictions
    2. Not many obligations and/or restrictions.
68. Safety laws. In considering equipment alternatives, applicable safety laws should not be forgotten. For example, in a highly automated "storage machine," an extensive "sprinkler system" for fire prevention is required.

With the help of these foregoing factors, selection decisions can be made in the following steps of the procedure.

5-2-2. Step 2. Select the Appropriate Warehouse Type

Before determining the appropriate equipment for a particular warehouse situation, it is important to know what type of warehouse is appropriate to that situation. Seven alternative warehouse types were shown in Figure 4. This step of the selection procedure is graphically shown in Figure 16. Which of the seven warehouse types is applicable depends on a number of factors. These factors can be selected from

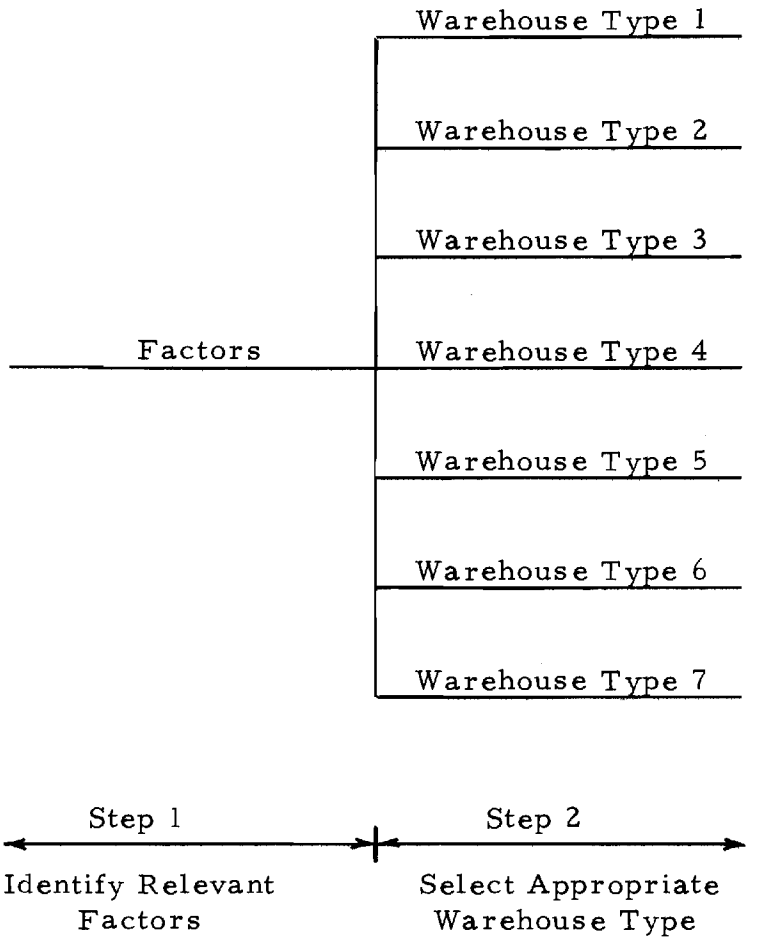


Figure 16. Steps 1 and 2 of the Selection Procedure.

the list of factors relevant to the selection of warehouse equipment as compiled in Step 1. This is done in Appendix D.

The result consists of the following list of factors:[1]

1. Type of material
2. Shape and/or form of handling units
3. Dimensions of handling units
4. Uniformity of handling units

[1] For a description of these factors, see Section 5-2-1.

5. Total average quantity
6. Quantity per delivery (from supplier) per item
7. Quantity per order per item
8. Peak quantities
9. External factors
10. Stock quantities per item
11. Number of orders per day
12. Required order delivery time
13. Competitors warehouse.

With the help of the above factors, a "Determination Sheet for the Selection of the Warehouse Type" has been developed. This is shown in Figure 17. The determination sheet can help the analyst to consider all of the identified factors in making a choice. First, the factors presented should be checked for applicability with respect to the particular situation. Second, the analyst should decide on the value of each factor. For example, for the factor, "total average quantity," he should decide whether this factor can be classified as "low," "medium," or "high" for his particular situation (see Figure 17, Factor 5). Third, the alternatives can be checked for applicability with respect to a certain factor by making a check mark. This can be done by circling the cross marks in the chart. In this way each circle indicates an argument in favor of an alternative.

The cross marks in the chart have been placed to guide the analyst in filling out the sheet. They identify arguments in a general situation. For example, in Figure 17 where Factor 6, "quantity per delivery (from supplier) per item," has been classified as "less than one unit load," cross marks have been placed under Alternatives 1 and 4. These cross

marks identify the argument that it is impossible to have Alternatives 2, 3, 5, 6, and 7 (with a flow consisting of unit loads into the storage area) if the delivered quantity per item is too small to build up unit loads. However, it is emphasized that the analyst should determine whether the general cross marks are valid for this particular situation.

As this sheet is filled out, a good impression of the various arguments in favor of the different alternatives can be obtained. Based on these arguments, the analyst can make a decision.

Two techniques have been suggested for making this decision on the basis of a quantitative figure:

1. The number of check marks for each alternative has been used as a selection variable by Bazaraa (5) and Rivera (13). However, this figure represents only the number of arguments in favor of a particular alternative and does not mean anything with respect to the importance of the argument(s). The use of this method is valid only if the following statement is true: The likelihood that an alternative (a) is preferable to another alternative (b) increases as the amount by which the number of check marks for alternative (a) exceeds those for alternative (b) increases.

   Example: If alternative (a) has 15 check marks and alternative (b) has only one check mark, it is likely that alternative (a) is preferable to alternative (b). If alternative (a) has 15

Date:_____ Analyst:_____ Firm:_____

Factors		Warehouse Types	1	2	3	4	5	6	7
1. Type of Material		unit	x	x	x	x	x	x	x
		bulk	-	-	-	-	-	-	-
		gas	-	-	-	-	-	-	-
		liquid	-	-	-	-	-	-	-
2. Shape/Form of Handling Units	Flow 1[1]	regular	x	x	x	x	x	x	x
		irregular	x			x			
	Flow 2[1]	regular	x	x	x	x	x	x	x
		irregular	x	x		x	x	x	
	Flow 3[1]	regular	-	-	-	x	x	x	x
		irregular	-	-	-	x	x		
3. Dimensions of Handling Units	Flow 1	small	x			x			
		medium	x	x	x	x	x	x	x
		large		x	x		x	x	x
	Flow 2	small	x	x		x	x	x	
		medium	x	x	x	x	x	x	x
		large			x				x
	Flow 3	small	-	-	-	x	x	x	
		medium	-	-	-	x	x	x	x
		large	-	-	-			x	x
4. Uniformity of Handling Units	Flow 1	1 fixed size	x	x	x	x	x	x	x
		variable sizes	x			x			
	Flow 2	1 fixed size	x	x	x	x	x	x	x
		variable sizes	x	x		x	x	x	
	Flow 3	1 fixed size	-	-	-	x	x	x	x
		variable sizes	-	-	-	x	x		
5. Total Average Quantity		low	x	x		x	x		
		medium	x	x	x	x	x	x	
		high			x			x	x
6. Quantity per Delivery (from supplier) per Item	less than 1 unit load		x			x			
	more than 1 unit load			x	x		x	x	x

Figure 17. Determination Sheet for the Selection of the Warehouse Type (page 1 of 2).

7. Quantity per Order per Item	less than 1 unit load	x	x		x	x	x	
	more than 1 unit load			x				x
8. Peak Quantities	low: less than 2 x average quantity	x	x	x				
	high: more than 2 x average quantity				x	x	x	x
9. External Factors	9a							
	9b							
10. Stock Quantities per Item (average)	low	x	x	x				
	medium	x	x	x	x	x	x	x
	high			x	x	x	x	x
11. Number of Orders per Day	low: 1-100	x	x	x				
	medium: 100-300				x	x	x	x
	high: over 300				x	x	x	x
12. Required Order Delivery Time (service degree)	short: less than 1 day			x	x	x	x	x
	long: more than 1 day	x	x					
13. Competitor's Warehouse	Type 1	x						
	Type 2		x					
	Type 3			x				
	Type 4				x			
	Type 5					x		
	Type 6						x	
	Type 7							x
	TOTAL							

[1]See Figure 4.

Figure 17. Determination Sheet for the Selection of the Warehouse Type (page 2 of 2).

check marks and alternative (b) has 14 marks, the likelihood that alternative (a) is better is about the same as the likelihood that alternative (b) is better.

Although a choice can be made by counting the number of check marks, the analyst can never be certain whether the optimum choice has been made. The probability that the outcome is correct can be increased by assuring that there is a significant difference in the number of check marks for the different alternatives. Moreover, the selection has to be checked on the basis of the particular arguments as identified by the marks in the sheet.

2. The importance of each alternative can be expressed by a number. Frazao (14) develops a complicated method by which the importance of a factor is derived from a number of "principles of materials handling." In this way, the marks in the chart can be replaced by numbers signifying the importance of each argument. The total of all of these numbers for an alternative is used as a selection variable.

   This method can be used in a simple way by grading the arguments that were identified by the marks according to the opinion of the analyst. A grading scale of 10 points is suggested with 10 representing very important and 1 representing very unimportant. The alternative with the highest total should be

selected.

For the purpose of the approach described in this study, both methods can be used.

1. Counting the number of check marks might give a rough indication, if the condition described on the previous page is fulfilled.
2. Grading the arguments according to personal opinion results in a quantitative selection variable that leads to the selection of the alternative with the highest score based on the combined importance of the arguments.

If the most appropriate warehouse type(s) are selected, this result should be compared with the existing situation. If the existing warehouse is of a type as selected, the next step of the procedure can be carried out in order to make the best equipment selection. However, if the existing warehouse is not of a type as selected, the analyst has to consider all of the possibilities for improving the whole warehouse system before selecting a piece of equipment for a sub-system. Apple (8) presents an extensive outline for analyzing and solving these problems. In this outline, equipment selection is only a sub-step.

5-2-3. Step 3. Select the Class of Mechanization/Automation

A rough indication of the applicable equipment alternatives can be obtained from the determination of the appropriate class of mechanization/automation. Three alternative classes were presented in Chapter IV, Section 4-2-3 (manual, mechanized, and automated). This step of

the selection procedure is graphically shown in Figure 18.

The general characteristics of the three classes are:

1. Manual. The operator is the main source of power. He may have the help of a simple mechanism.
2. Mechanized. The work is done with the help of external power. The operator controls the equipment.
3. Automated. The control is no longer manual.

Which class of mechanization/automation is the most appropriate depends on a number of factors. These factors can be identified from the list of factors relevant to the selection of warehouse equipment which was compiled in Step 1. This is done in Appendix E.

The result consists of the following list of factors:[1]

1. Type of material
2. Shape and/or form of handling units
3. Dimensions of handling units
4. Uniformity of handling units
5. Weight of handling units
6. Total average quantity
7. Area involved
8. Distance of the move
9. Frequency distribution
10. Likelihood of change of product or product mix
11. Present information system/record-keeping system
12. Total storage space
13. Number of line items stored
14. Future expansions
15. Number of orders per day
16. Required order delivery time
17. General economic conditions
18. Growth potential and trends
19. Competitors warehouse

---

[1] For a description of these factors, see Section 5-2-1.

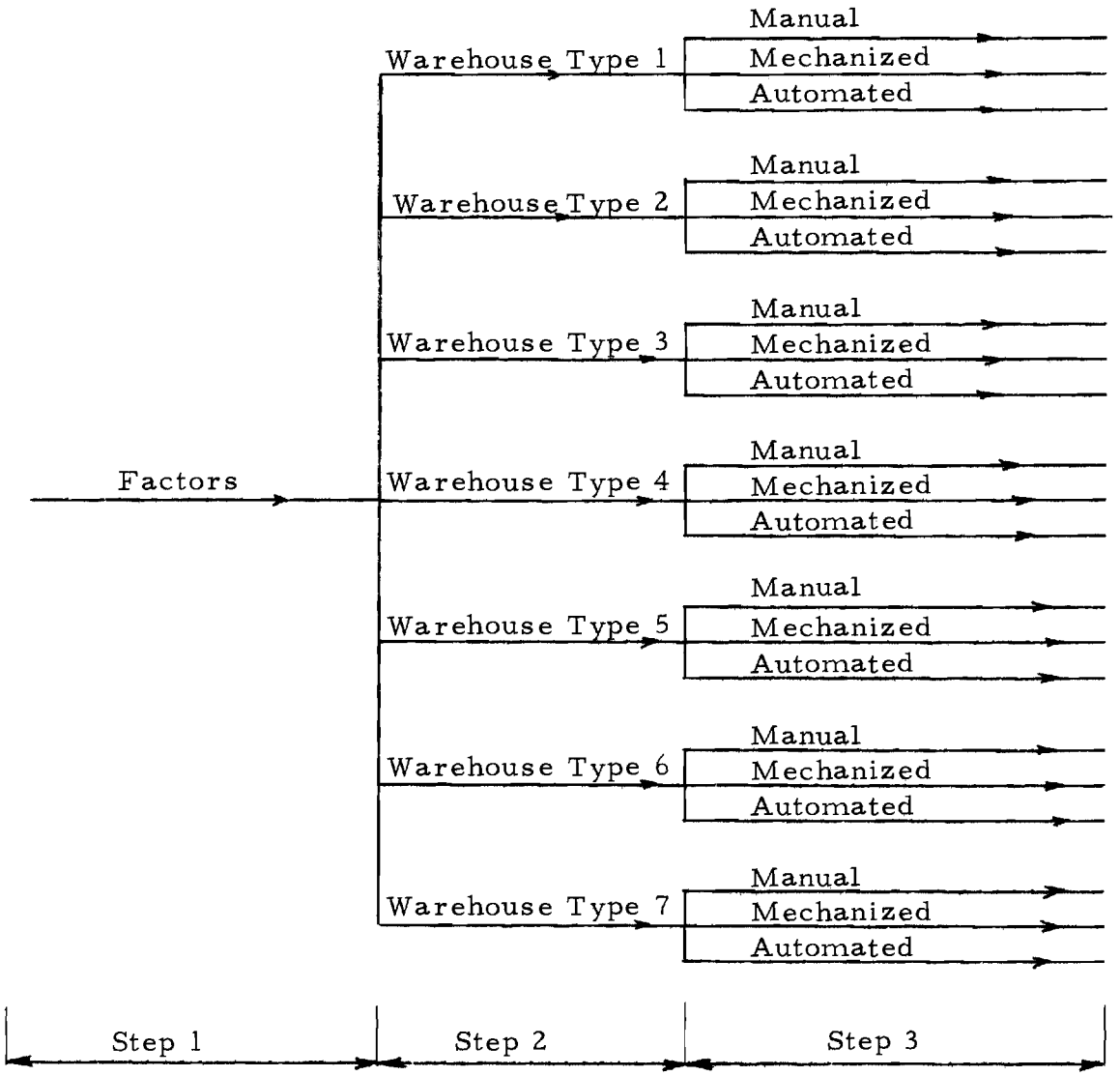


Figure 18. Steps 1, 2, and 3 of the Selection Procedure.

20. Wages
21. Employees' attitude
22. Management attitude
23. Comfort and fatigue
24. Monotony of job
25. Financial policy
26. Labor market.

With the help of the foregoing factors, a "Determination Sheet for the Selection of the Class of Mechanization/Automation" has been developed. This is shown in Figure 19. The use of the sheet is similar to that in the previous step:

1. The presented factors should be checked for applicability to the situation.
2. For every factor, its value should be determined.
3. Alternatives should be checked for applicability with respect to a particular factor by placing circle marks. Again, marks represent favorable arguments.
4. The check marks for each alternative should be totaled to determine whether there is a substantial difference in these totals among the various alternatives. If this is the case, an indication can be found.
5. The rough indication resulting from Step 4 can be verified and a more refined selection can be made by grading the arguments in accordance with their relative importance and using the sum of the grades per alternative (the total score) as a selection variable.

In addition, a sixth step is suggested:

6. Having selected one or more alternatives, the arguments that caused the high total score should be identified and their grading should be evaluated with respect to the other

Result Step 2: Warehouse Type _____

Activity: _____

Date: _____ Analyst: _____ Firm: _____

Factors	Warehouse Types	Manual	Mechan-ized	Auto-mated
1. Type of Material	unit bulk gas liquid			
2. Shape/Form of Handling Units	regular irregular			
3. Dimensions of Handling Units	small medium large			
4. Uniformity of Handling Units	1 fixed size variable sizes			
5. Weight of Handling Unit	0-50 pounds over 50 pounds			
6. Total Quantity, Average	low medium high			
7. Area Involved	small medium large			

Figure 19. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 1 of 3).

8.	Distance of Move	short: under 100 feet medium: 100-300 feet large: over 300 feet			
9.	Frequency Distribution	constant volume variable volume highly variable volume			
10.	Likelihood of Change of Product or Product Mix	stable change within 5 years change within 1 year			
11.	Present Information System/ Record Keeping System	computerized not computerized			
12.	Total Storage Space	small medium large			
13.	Number of Line Items Stored	1-200 200-3,000 3,000-10,000 over 10,000			
14.	Future Expansion	yes no			
15.	Number of Orders per Day	low medium high			
16.	Required Order Delivery Time	short long			

Figure 19. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 2 of 3).

17. General Economic Conditions	favorable unfavorable			
18. Growth Potential and Trends	favorable constant unfavorable			
19. Competitor's Warehouse	manual mechanized automated			
20. Wages	low medium high			
21. Employees' Attitude	positive indifferent negative			
22. Management's Attitude	positive indifferent negative			
23. Comfort and Fatigue	good situation bad situation			
24. Monotony of Job	monotonous not monotonous			
25. Financial Policy	investment/spending save			
26. Labor Market	favorable unfavorable			
				TOTAL

Figure 19. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 3 of 3).

arguments. As the analyst considers the results of the grades he gave the first time, he may want to regrade some of the arguments. After regrading, the total score can be recomputed, leading to the final selection. For an example of an application, see Chapter VII, Section 7-4.

5-2-4. Step 4. Select the Level of Mechanization/Automation

Compared with the class of mechanization/automation, the level of mechanization/automation gives a more refined impression of the applicable equipment alternatives. The levels were presented in Chapter IV, Section 4-2-1 (the 10 levels as developed by Bazaraa). Adding the determination of the level of mechanization/automation as a fourth step results in a selection procedure as shown in Figure 20.

Which level is the most appropriate depends on a number of factors. These factors can be identified from the list of factors relevant to the selection of warehouse equipment which was compiled in Step 1. This is done in Appendix F. The result consists of the following list of factors:[1]

1. Shape and/or form of handling unit
2. Dimensions of handling units
3. Uniformity of handling units
4. Weight of handling units
5. Fragility of material
6. Total average quantity
7. Peak quantities
8. Seasonality

---

[1]For a description of the factors, see Section 5-2-1.

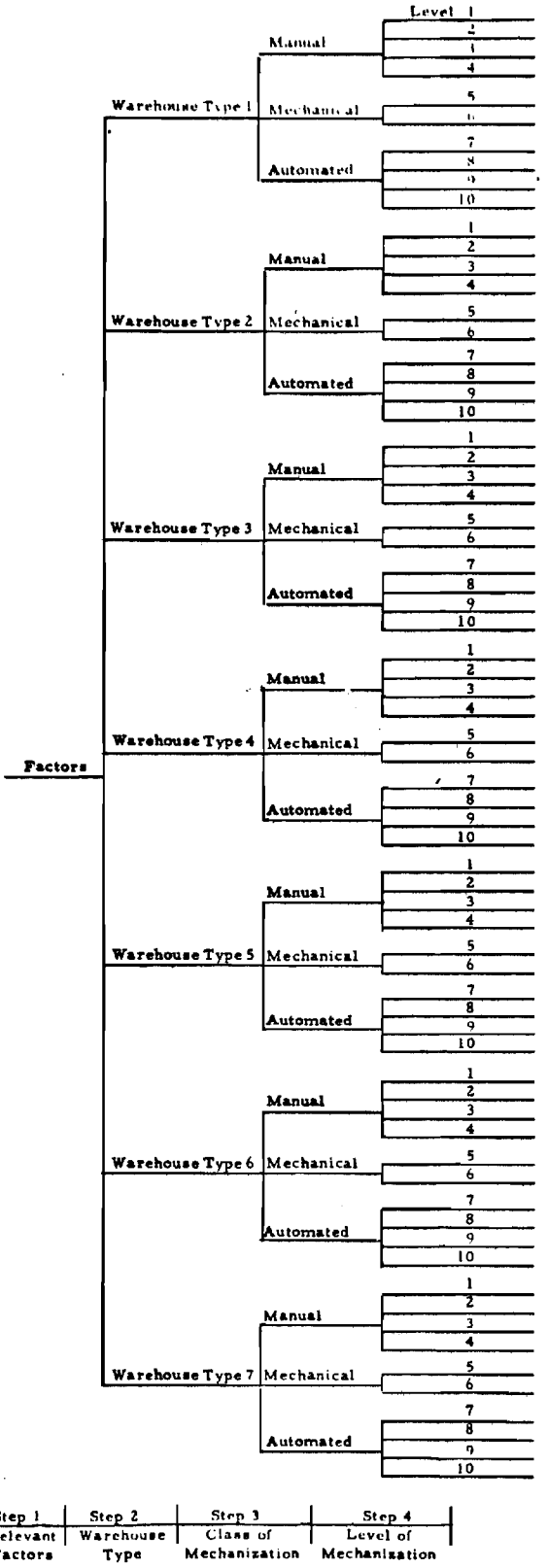


Figure 20. Steps 1, 2, 3, and 4 of the Selection Procedure.

9. Frequency distribution
10. Area involved
11. Complexity of activity (activities)
12. Path
13. Number of origins and number of destinations
14. Distance of move
15. Cross traffic
16. Aisle width
17. Ceiling height/clear height
18. Column spacing
19. Column load capacity
20. Floor-running surface
21. Likelihood of change of product or product mix
22. Record-keeping system/information system
23. Total storage space
24. Number of line items stored
25. Future expansions
26. General economic conditions
27. Growth potential and trends
28. Competitors' activities
29. Physical requirements and fatigue
30. Skill required
31. Wages
32. Employees' attitude towards mechanization/automation
33. Managers' attitude towards mechanization/automation
34. Noise produced
35. Monotony of job
36. Financial policy
37. Labor market.

With the help of the above factors, a "Determination Sheet for the Selection of the Level of Mechanization/Automation" has been developed. This is shown in Figure 21. This sheet can be used to select the appropriate level(s) of mechanization/automation. The use of the sheet is exactly the same as described in the previous step.

5-2-5. Step 5. Select the Specific Type of Equipment

After determination of the most appropriate level of mechanization/automation, the equipment alternatives for a particular activity

Result Step 2: Warehouse Type: _____
Activity: _____
Result Step 3: _____ (Manual, Mechanized, or Automated)

Date: _____ Analyst: _____ Plant: _____

Factors \ Class / Level		Manual				Mech.		Automated			
		1	2	3	4	5	6	7	8	9	10
1. Shape/ Form of Handling Units	regular	x	x	x	x	x	x	x	x	x	x
	irregular	x	x	x	x	x	x				
2. Dimensions of Handling Units	small	x	x	x	x	x	x	x	x	x	x
	medium		x	x	x	x	x	x	x	x	x
	large			x		x	x				
3. Uniformity of Handling Units	1 fixed size	x	x	x	x	x	x	x	x	x	x
	variable sizes	x	x	x	x	x	x	x			
4. Weight of Handling Units	0-50 pounds	x	x	x	x		x	x	x	x	x
	50-1,000 pounds		x	x	x	x	x	x	x	x	x
	1,000-10,000 pounds					x	x	x	x	x	x
	over 10,000 pounds						x				
5. Fragility of Material	fragile	x	x	x		x		x	x	x	x
6. Total Average Quantity	low	x	x	x	x						
	medium		x	x	x	x	x	x			
	high				x	x	x	x	x	x	x

Figure 21. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 1 of 5).

7. Peak Quantities	high	x	x	x	x	x	x					
	low	x	x	x	x	x	x	x	x	x	x	
8. Seasonality	constant	x	x	x	x	x	x	x	x	x	x	
	season variations	x	x	x	x	x	x	x	x	x	x	
	high season variations	x	x	x	x	x						
9. Frequency Distribution	constant	x	x	x	x	x	x	x	x	x	x	
	variable	x	x	x	x	x	x	x	x			
	highly variable	x	x	x	x	x	x					
10. Area Involved	small	x	x	x	x	x		x	x	x	x	
	medium		x	x	x	x	x	x	x	x	x	
	large					x	x	x	x	x	x	
11. Complexity of Activity (Activities)	simple	x	x	x	x	x	x	x	x	x	x	
	complex	x	x	x		x	x	x	x	x	x	
	very complex	x	x			x						
12. Path	simple	x	x	x	x	x	x	x	x	x	x	
	compound	x	x	x		x	x	x	x	x	x	
	complex	x	x	x		x			x	x	x	
13. Number of Origins and Number of Destinations	one or a few	x	x	x	x	x	x	x	x	x	x	
	many	x	x	x		x	x	x	x	x	x	
14. Distance	short: under 100 ft.	x	x	x	x	x	x	x	x	x	x	
	medium: 100-300 feet		x	x	x	x	x	x	x	x	x	
	long: over 300 feet					x	x	x	x	x	x	
15. Cross Traffic	much cross traffic	x	x	x		x	x	x	x	x	x	
	not much cross traffic	x	x	x	x	x	x	x	x	x	x	
16. Aisle Width	narrow: under 6 ft.	x	x	x	x	x		x	x	x	x	
	wide: over 6 feet	x	x	x	x	x	x	x	x	x	x	

Figure 21. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 2 of 5).

17.	Ceiling Height/ Clear Height	low: under 12 feet	x	x	x	x	x		x	x	x	x		
		medium: 12-20 ft.	x	x	x	x	x	x	x	x	x	x		
		high: over 20 feet					x	x	x	x	x	x		
18.	Column Spacing	small: less than 15 feet	x	x	x	x	x		depends on type of equipment					
		medium: 15-30 feet	x	x	x	x	x							
		large: over 30 feet	x	x	x	x	x	x						
19.	Column Load Capacity	low: less than 2,000 pounds	x	x	x	x	x		depends on type of equipment					
		medium: 2,000-10,000 pounds	x	x	x	x	x	x						
		high: over 10,000 pounds	x	x	x	x	x	x						
20.	Floor-Running Surface	smooth		x			x		depends on type of equipment					
		not important	x		x	x		x						
21.	Likelihood of Change of Product or Product Mix	stable	x	x	x	x	x	x	x	x	x	x		
		change within 5 years	x	x	x	x	x							
		change within 1 year	x	x	x	x								
22.	Record Keeping System/ Information System	not computerized	x	x	x	x	x	x	x					
		computerized	x	x	x	x	x	x	x	x	x	x		
23.	Total Storage Space	small	x	x	x	x	x	x						
		medium	x	x	x	x	x	x	x					
		large					x	x	x	x	x	x		
24.	Number of Line Items Stored	1-200	x	x	x	x	x	x						
		200-3,000	x	x	x	x	x	x						
		3,000-10,000					x	x	x	x				
		over 10,000						x	x	x	x	x		

Figure 21. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 3 of 5).

25.	Future Expansion	yes	x	x	x	x	x	x	x	x	x	x
		no	x	x	x	x	x	x	x			
26.	General Economic Conditions	favorable					x	x	x	x	x	x
		unfavorable	x	x	x	x						
27.	Growth Potential and Trends	high					x	x	x	x	x	x
		normal	x	x	x	x	x	x	x			
		low	x	x	x	x						
28.	Competitors' Activities	Level 1	x	x								
		Level 2	x	x	x							
		Level 3		x	x	x						
		Level 4			x	x	x					
		Level 5				x	x	x				
		Level 6					x	x	x			
		Level 7						x	x	x		
		Level 8							x	x	x	
		Level 9								x	x	x
		Level 10									x	x
29.	Physical Requirements and Fatigue	low				x	x	x	x	x	x	x
		medium		x	x							
		high	x	x								
30.	Skill Required	low	x	x	x	x	x	x	x	x		
		medium					x	x	x	x	x	x
		high							x	x	x	x
31.	Wages	low	x	x	x	x	x	x				
		medium					x	x	x	x		
		high					x	x	x	x	x	x
32.	Employees' Attitude towards Mechanization/ Automation	negative										
		indifferent		x	x	x	x	x				
		positive		x	x	x	x	x				

Figure 21. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 4 of 5).

33.	Managers' Attitude towards Mechanization/ Automation	negative									
		indifferent		x	x	x	x	x	x		
		positive		x	x	x	x	x	x	x	x
34.	Noise Produced	high					x				
		low	x	x	x	x	x	x	x	x	x	x
35.	Monotony of Job	monotonous	x	x	x			x	x	x	x
		not monotonous	x	x	x	x	x	x	x	x	x	x
36.	Financial Policy	spend/invest					x	x	x	x	x	x
		save on investments	x	x	x	x						
37.	Labor Market	easy to get labor	x	x	x		x	x				
		difficult to get labor				x	x	x	x	x	x	x
TOTAL												

Figure 21. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 5 of 5).

can be identified from the "overviews of Equipment Alternatives" as described in Chapter IV and illustrated in Appendix B. For example, in Appendix B, under Sub-function 2, "to bulk storage," if one looks down the activity column "to bulk storage location," the following alternatives are shown for the level of mechanization/automation 5, "power equipment, hand control":

1. Fork truck
2. Conveyors, different types
3. Tractor train
4. Hand controlled stacker crane.

Adding the selection of the specific type(s) of equipment as a fifth step results in a selection procedure as graphically shown in Figure 15 on page 53.

Which of the identified alternatives is the most appropriate depends on a number of factors. These factors have been identified in Step 1. With the help of these factors, a "Determination Sheet for the Selection of the Specific Type of Warehouse Equipment" has been developed. The result is shown in Figure 22.

The function of this determination sheet is to guide the analyst in his consideration of all of the factors related to making the final choice of equipment type. The use of the sheet is exactly the same as described in Section 5-2-3.

Result Step 2: Warehouse Type No. _____
Activity or Activities: _____
Result Step 3: _____ (Manual, Mechanized, or Automated)
Result Step 4: Level of Mechanization/Automation _____

_____

Date: _____ Analyst: _____ Firm: _____

Factors \ Equipment Alternatives		1	2	
1. Type of Material	unit bulk liquid gas			
2. Shape/Form of Handling Units	regular irregular			
3. Dimensions of Handling Units	small medium large			
4. Uniformity of Handling Units	1 fixed size variable sizes			
5. Total Average Quantity	low medium high			
6. Number of Orders per Day	low: 1-100 medium: 100-300 high: over 300			
7. Quantity per Delivery (from supplier) per Item	less than 1 unit load more than 1 unit load			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 1 of 7).

8. Quantity per Order per Item	less than 1 unit load more than 1 unit load			
9. Peak Quantities	low: less than 2 x average quantity high: more than 2 x average quantity			
10. External Factors				
11. Stock Quantities per Item	low medium high			
12. Order Delivery Time	short: less than 1 day long: more than 1 day			
13. Competitor's Warehouse				
14. Weight of Handling Unit	under 50 pounds 50-1,000 pounds 1,000-10,000 pounds over 10,000 pounds			
15. Area Involved	small medium large			
16. Distance of Move	under 100 feet 100-300 feet over 300 feet			
17. Frequency Distribution	no variability low variability high variability			
18. Likelihood of Change of Product or Product Mix	stable change within 5 years change within 1 year			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 2 of 7).

19.	Present Information System/ Record Keeping System	computerized not computerized			
20.	Total Storage Space		small medium large		
21.	Number of Line Items Stored	under 200 200-3,000 3,000-20,000 over 10,000			
22.	Future Expansions		yes no		
23.	General Economic Conditions	favorable unfavorable			
24.	Growth Potential and Trends	favorable constant unfavorable			
25.	Wages	low medium high			
26.	Employees' Attitude	negative indifferent positive			
27.	Management's Attitude	negative indifferent positive			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 3 of 7).

28.	Comfort and Fatigue	good situation bad situation			
29.	Monotony of Job	monotonous not monotonous			
30.	Financial Policy	investment/spending save			
31.	Labor Market	favorable unfavorable			
32.	Fragility of Material	fragile			
33.	Seasonality	constant quantity variable quantities highly variable quantities			
34.	Complexity of Activity (Activities)	simple complex very complex			
35.	Path	simple compound complex			
36.	Number of Origins and Number of Destinations	one or a few many			
37.	Cross Traffic	much not much			
38.	Aisle Width	narrow: under 6 feet wide: over 6 feet			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 4 of 7).

39.	Ceiling Height/ Clear Height	low: under 12 feet medium: 12-20 feet high: over 20 feet			
40.	Column Spacing	small: under 15 feet medium: 15-30 feet large: over 30 feet			
41.	Column Load Capacity	low: under 2,000 lbs. medium: 2,000-10,000 lbs. high: over 10,000 lbs.			
42.	Floor Running Surface	smooth rough			
43.	Skill Required	low medium high			
44.	Noise Produced	low noise level high noise level			
45.	Levels of Route	1 2-5 over 5			
46.	Sequence of Moves	fixed variable			
47.	Dimensions of Building	small medium large			
48.	Shape of Building	square rectangular other			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 5 of 7).

49.	Number of Floors	one more than one			
50.	Space Available for Equipment		small medium large		
51.	Construction of Building		steel concrete other		
52.	Legal Requirements	special measures no special measures			
53.	Number of Aisles	a few many to be determined			
54.	Location of Aisles	fixed to be determined			
55.	Stacking Height	low: under 12 feet medium: 12-20 feet high: over 20 feet			
56.	Floor Weight Limits	low: under 250 psi medium: 250-1,000 psi high: over 1,000 psi			
57.	Ramps				
58.	Sales Unit of Product	can be handling unit cannot be handling unit			
59.	Package Characteristics	package can be handling unit packages can be arranged into unit load package is difficult to handle			

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 6 of 7).

60. Shipping and Receiving Schedule					
61. Carrier Caracteristics					
62. Inventory Policy					
63. Motivation and Satisfaction		low normal high			
64. Heat Produced	unacceptable acceptable				
65. Injuries	safe dangerous				
66. Union Attitude	positive indifferent negative				
67. Labor Legislation	many obligations/ restrictions not many obligations/ restrictions				
68. Safety Laws					
TOTAL					

Figure 22. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 7 of 7).

CHAPTER VI

CONSOLIDATION OF THE STEPS OF THE PROCEDURE

In order to obtain an overview of the whole method, the determination sheets of Steps 2, 3, 4, and 5 have been combined into one master chart. This chart is shown in Appendix G.

The different alternatives of Steps 2, 3, 4, and 5 are plotted horizontally, and the factors vertically. In comparison with Chapter V, the sequence of the factors has been changed in order to divide the total number of factors into groups. Each group of factors is relevant to a particular step. For example, Factors 1-13 are relevant to Step 1, etc.

The method of equipment selection with this chart is the same as the method with the four determination sheets described in Chapter V. Step 1 has already been made; the result is the list of factors in the chart. Consequently, Step 2 is carried out first, followed by Step 3. Since the result of Step 2 does not directly influence the alternatives in Step 3, the check marks for a particular factor can be placed at the same time for Steps 2 and 3. Third, Step 4 can be carried out. Only those alternatives indicated by the result of Step 3 have to be taken into account. Finally, Step 5 can be carried out.

This chart has two advantages:

1. The analyst has a clear overview of the whole procedure during the selection process.
2. The check marks for Steps 2 and 3 for a particular factor can be placed at the same time.

A disadvantage is that the chart is quite large, which limits the practical applicability.

Whether to use this overview or to use the individual determination sheets for the different steps is a decision left with the analyst.

CHAPTER VII

THE SELECTION OF ORDER PICKING EQUIPMENT FOR A WAREHOUSE FOR GRAMOPHONE RECORDS

7-1. Introduction

To test the developed method, it is applied to a problem in an existing warehouse situation. The characteristics of this situation are summarized in Table 6. It represents a warehouse for gramophone records in Amsterdam, The Netherlands, which serves as the distribution center for the Dutch market for Phonogram-Nederland and Polydor-Nederland Companies. The problem is to investigate whether the item-picking activity (which is done completely manually) can be done with the help of some type of equipment. This application has the primary purpose of illustrating the developed equipment selection method.

7-2. The Selection Procedure Applied

7-2-1. Step 1. Identify All of the Relevant Factors

The factors relevant to the general problem of equipment selection have been identified in Appendix C. These factors have been compiled into a list that forms the basis for all of the following steps. This list is shown in Chapter V.

Table 6. Warehouse for Gramophone Records: Most Important Characteristics (simplified)[1]

- Dimensions of record--outer sleeve: 12.2 x 12.2 x 0.15 inches (12-inch record).
- Total average quantity throughput: 9×10^6 records/year = 36,000 records/day.
- Peak quantities: estimated at up to 10,000 records/hour.
- Seasonality: throughput in the first eight months of the year is equal to throughput of the last four months.
- Quantity per delivery (from supplier) per item: from 500 to 5,000 records.
- Quantity per customer order per item: average of 10 records.
- Dimensions of building: the warehouse has recently been moved into a storage area of 350 x 350 x 10 feet (estimation), which comprises the first floor of a multi-level building.
- The company does not expect the product (gramophone record) to change within the next five years.
- The warehouse has some experience with the application of "program"-controlled conveyors for long moves.
- Stock quantities: 9×10^5 records (estimation).
- Number of line items stored: 3,500.
- Future expansion: there are plans to add some smaller warehouse activities that currently are done elsewhere, but the overall warehouse function of the company is not expected to change suddenly in the future.
- The labor market is very difficult or "tight" in Amsterdam.
- Competition does item picking by hand.
- Record-keeping system and information system have been computerized.
- Number of orders per day: (average) 600.
- Average order quantity: 170 records.

[1] For a more detailed description, see (11).

7-2-2. Step 2. Select the Appropriate Warehouse Type

In Chapter III, seven different warehouse types were distinguished. These seven alternatives can be related to the relevant factors with the help of a Determination Sheet for the Selection of the Appropriate Warehouse Type as developed in Section 5-3. This is shown in Figure 23. The results of Figure 23 are summarized in Table 7.

Table 7. A Summary of the Warehouse Types

Warehouse Type	1	2	3	4	5	6	7
Number of Check Marks	13	10	9	18	14	14	11

Table 7 indicates that Type 4 is the best choice. Its lead over the second choice is 18 minus 14 or 4 points. With respect to the 18 points of Type 4, this difference is 22 per cent. It is debatable whether this difference is significant enough to draw the conclusion that Type 4 is the most appropriate alternative. Types 5 and 6 are the closest competitors.

To check this conclusion, Alternatives 4, 5, and 6 can be compared in greater detail. The following arguments in favor of Type 4 can be identified from Figure 23:

1. Factor 3. Dimensions of handling unit. Type 4 is appropriate

Date:_____ Analyst:_____ Firm:_____

Activity:_____

Factors			Warehouse Types 1	2	3	4	5	6	7
1. Type of Material		unit	⊗	⊗	⊗	⊗	⊗	⊗	⊗
		bulk	-	-	-	-	-	-	-
		gas	-	-	-	-	-	-	-
		liquid	-	-	-	-	-	-	-
2. Shape/Form of Handling Units	Flow 1[1]	regular	⊗	⊗	⊗	⊗	⊗	⊗	⊗
		irregular	x			x			
	Flow 2[1]	regular	⊗	⊗	⊗	⊗	⊗	⊗	⊗
		irregular	x	x		x	x	x	
	Flow 3[1]	regular	-	-	-	⊗	⊗	⊗	⊗
		irregular	-	-	-	x	x		
3. Dimensions of Handling Units	Flow 1	small	⊗			⊗			
		medium	x	x	x	x	x	x	x
		large		x	x		x	x	x
	Flow 2	small	⊗	⊗		⊗	⊗	⊗	
		medium	x	x	x	x	x	x	x
		large			x				x
	Flow 3	small	-	-	-	⊗	⊗	x	
		medium	-	-	-	x	x	x	x
		large	-	-	-			x	x
4. Uniformity of Handling Units	Flow 1	1 fixed size	⊗	⊗	⊗	⊗	⊗	⊗	⊗
		variable sizes	x			x			
	Flow 2	1 fixed size	⊗	⊗	⊗	⊗	⊗	⊗	⊗
		variable sizes	x	x		x	x	x	
	Flow 3	1 fixed size	-	-	-	⊗	⊗	⊗	⊗
		variable sizes	-	-	-	x	x		
5. Total Average Quantity		low	x	x		x	x		
		medium	⊗	⊗	⊗	⊗		⊗	
		high			x			x	x
6. Quantity per Delivery (from supplier) per Item	less than 1 unit load		⊗			⊗			
	more than 1 unit load			x	x		x	x	x

Figure 23. Determination Sheet for the Selection of the Warehouse Type. (page 1 of 2).

7. Quantity per Order per Item	less than 1 unit load	⊗	⊗		⊗	⊗	⊗		
	more than 1 unit load			x				x	
8. Peak Quantities	low: less than 2 x average quantity	x	x	x					
	high: more than 2 x average quantity				⊗	⊗	⊗	⊗	
9. External Factors	Items change in popularity	⊗	⊗	⊗					
10. Stock Quantities per Item (average)	low	x	x	x					
	medium	⊗	⊗	⊗	⊗	⊗	⊗	⊗	
	high			x	x	x	x	x	
11. Number of Orders per Day	low: 1-100	x	x	x					
	medium: 100-300				x	x	x	x	
	high: over 300				⊗	⊗	⊗	⊗	
12. Required Order Delivery Time (service degree)	short: less than 1 day			⊗	⊗	⊗	⊗	⊗	
	long: more than 1 day	x	x						
13. Competitor's Warehouse	Type 1	⊗							
	Type 2		x						
	Type 3			x					
	Type 4				⊗				
	Type 5					x			
	Type 6						x		
	Type 7							x	
TOTAL		13	10	9	18	14	14	11	

[1] See Figure 4.

Figure 23. Determination Sheet for the Selection of the Warehouse Type. (page 2 of 2)

for small handling units like gramophone records. Types 5 and 6 are not.

2. Factor 5. Total average quantity. Since this parameter can be classified as medium (in the record business), Type 5 is not appropriate with respect to this factor.
3. Factor 6. Quantity per delivery (from supplier) per item. Since this parameter can be classified as less than one unit load, Types 5 and 6 are not appropriate.
4. Factor 13. Competitor's warehouse. The competition uses two types of warehouses: Type 1 and Type 4.

Figure 23 gives no other arguments in favor of Types 5 and 6.

Conclusion. On the basis of the reasons mentioned above, Type 4 can be selected without further investigation. Since the existing warehouse is of Type 4, the selection procedure can be continued.

7-2-3. Step 3. Select the Appropriate Class of Mechanization/Automation

In Chapter IV, three classes of mechanization/automation were distinguished:

- Manual
- Mechanized
- Automated.

These three alternatives can be related to the relevant factors with the help of a Determination Sheet for the Selection of the Class of Mechani-

zation/Automation, as developed in Chapter V. This is shown in Figure 24 for the activity to be investigated--Item Picking. The results are shown in Table 8.

Table 8. A Summary of the Classes of Mechanization/Automation

Alternative	Number of Check Marks
Manual	13
Mechanized	18
Automated	12

Table 8 indicates that "mechanized" is the first choice in the selection procedure. The difference between this first choice and the second choice ("manual") is 18 minus 13 or 5 points, or 28 per cent with respect to the 18 points. This difference seems to be large enough to draw the following conclusion: "Mechanized" is the most appropriate alternative. "Manual" is the closest competitor.

To check this selection, the alternatives can be compared in greater detail by grading the arguments in order of importance. These grades are placed behind the cross marks in Figure 24. It must be emphasized that the grades represent the personal opinion of the

Result Step 2: Warehouse Type _____

Activity: Item Picking

Date: 7/1/73 Analyst: _____ Firm: X

Factors	Warehouse Types	Manual	Mechan-ized	Auto-mated
1. Type of Material	unit	⊗ 1	⊗ 1	⊗ 1
	bulk	-	-	-
	gas	-	-	-
	liquid	-	-	-
2. Shape/Form of Handling Units	regular	⊗ 1	⊗ 1	⊗ 1
	irregular	x	x	
3. Dimensions of Handling Units	small	⊗ 9/7		
	medium		x	x
	large		x	x
4. Uniformity of Handling Units	1 fixed size	⊗ 2	⊗ 1	⊗ 2
	variable sizes	x		
5. Weight of Handling Unit	0-50 pounds	⊗ 9/7		
	over 50 pounds		x	x
6. Total Quantity, Average	low	x	x	
	medium	⊗ 5	⊗ 5	⊗ 2
	high		x	x
7. Area Involved	small			
	medium	na	na	na
	large			

Figure 24. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 1 of 3).

8. Distance of Move	short	⊗ 9/7	x	x
	medium		x	x
	long		x	x
9. Frequency Distribution	constant volume		x	x
	variable volume	x	x	x
	highly variable volume	⊗ 9		
10. Likelihood of Change of Product or Product Mix	stable		⊗ 2	⊗ 2
	change within 5 years	x	x	
	change within 1 year	x		
11. Present Information System/ Record-Keeping System	computerized		x	⊗ 8
	not computerized	x	x	
12. Total Storage Space	small	x	x	
	medium		⊗ 2	
	large		x	x
13. Number of Line Items Stored	1-200	x	x	
	200-3,000	x	x	
	3,000-10,000		⊗ 4	1
	over 10,000		x	x
14. Future Expansion	yes		⊗ 6	⊗ 4
	no	x	x	x
15. Number of Orders per Day	low	x	x	
	medium	⊗ 4	⊗ 6	
	high		x	x
16. Required Order Delivery Time	short		⊗ 7/6	⊗ 7
	long	x	x	

Figure 24. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 2 of 3).

17. General Economic Conditions	favorable		⊗ 4/2	x
	unfavorable	x	x	
18. Growth Potential and Trends	favorable		x	x
	constant	⊗ 7/7	⊗ 4/1	x
	unfavorable	x	x	
19. Competitor's Warehouse	manual	⊗ 5	x	
	mechanized	x	x	x
	automated		x	x
20. Wages	low	x	x	
	medium	x	x	x
	high		⊗ 8	⊗ 9
21. Employees' Attitude	positive		⊗ 5/2	⊗ 5
	indifferent	x	x	x
	negative	x		
22. Management's Attitude	positive		x	x
	indifferent	⊗ 5	⊗ 5	⊗ 5
	negative	x		
23. Comfort and Fatigue	good situation	⊗ 2	⊗ 2	
	bad situation		x	x
24. Monotony of Job	monotonous		x	x
	not monotonous		x	
25. Financial Policy	investment/spending		⊗ 2	
	save	x	x	
26. Labor Market	favorable	x	x	
	unfavorable		⊗ 4/6	⊗ 4
Number of marks		13	18	12
Total score after grading		68	69	51
Total score after regrading		62	62	51

Figure 24. Determination Sheet for the Selection of the Class of Mechanization/Automation (page 3 of 3).

analyst (in this case the author) about the importance of the arguments. In practice, the quality of these judgments could be improved considerably by consultations with the warehouse manager, equipment manufacturers, and experienced engineers. Adding the grades for each alternative results in the following total scores:

1. Mechanized: 69 points
2. Manual: 68 points
3. Automated: 51 points.

This result confirms the foregoing preliminary selection.

To identify the reasons for this particular ranking, the arguments in favor of mechanized with respect to manual and the arguments in favor of manual with respect to mechanized have been summarized in Table 9.

As a result of the development of the main reasons for the above outcome, the grades for a few arguments have been changed somewhat. These revised grades have been placed in Figure 24 behind the original grades (the two numbers are separated by a slash (/) sign). This grading process leads to the following final score:

1. Mechanized: 62 points
2. Manual: 62 points
3. Automated: 51 points.

The grading process and the regrading process yield the same outcome. However, in both cases the difference between the first

Table 9. The Most Important Arguments in Favor of the First Choice "Mechanized" and the Second Choice "Manual"

Arguments in Favor of "Mechanized" with respect to "Manual"	Arguments in Favor of "Manual" with respect to "Mechanized"
1. Uniformity of handling units makes mechanization easy.	1. Dimensions of handling units are small, so units are easy to handle manually.
2. Present warehouse has a little experience with mechanization.	2. Weights of handling units are low.
3. Total storage space can be classified as medium.	3. Distance of item picking move is short.
4. Number of items stored is between 3,000 and 10,000.	4. Frequency distribution can be classified as highly variable volume (flow of materials).
5. Some reorganization (concentration of warehouses) is planned in the future.	5. The product's growth potential and trends are just constant.
6. Average number of orders per day can be classified as medium.	6. Competitor's item picking is manual.
7. Required order delivery time is short.	
8. General economic conditions are slightly favorable.	
9. Existing wages can be classified as high.	
10. Employees' attitude is positive.	

Table 9. The Most Important Arguments in Favor of the First Choice "Mechanized" and the Second Choice "Manual" (continued)

11. Financial policy reflects no reluctance to invest.	
12. Labor market is difficult.	
13. Product is not likely to change within 5 years.	

choice and the second choice is very slight (1 point and 0 points). For this reason, the decision is made to carry both the alternatives mechanized and manual over to the next step of the procedure.

7-2-4. Step 4. Select the Appropriate Level of Mechanization/Automation

Because in the previous step two classes of mechanization/automation were selected, a level of mechanization/automation must be selected from the following alternatives:

1. Manual
    a. Hand
    b. Hand equipment
    c. Mechanized hand equipment
    d. Gravity equipment
2. Mechanized
    a. Power equipment, hand control
    b. Power equipment, remote hand control.

The six alternatives can be related to the relevant factors with

the help of a Determination Sheet for the Selection of the Level of Mechanization/Automation as developed in Chapter V. This is done in Figure 25. The results are as follows:

Table 10. A Summary of the Levels of Mechanization/Automation

Alternative	Number of Check Marks
5. Power equipment, hand control	31
6. Power equipment, remote hand control	30
2. Hand equipment	29
3. Mechanized hand equipment	27
1. Hand	23
4. Gravity equipment	23

However, since the differences between the total number of check marks for the various alternatives are small (for example, 31 minus 30 or 1 point; with respect to 31, this is a 3 per cent difference), the conditions necessary to draw any conclusions from the number of check marks are not fulfilled. To make a choice, the arguments as identified by the check marks must be graded in accordance with their relative importance. These grades are placed behind the check marks in Figure 25. Adding the grades for each alternative results in the fol-

lowing total scores:

Table 11. A Summary of the Levels of Mechanization/Automation

Rank	Alternative	Total Score
1	1. Hand	106
2	6. Power equipment, remote hand control	101
3	4. Gravity equipment	85
4	5. Power equipment, hand control	84
5	2. Hand equipment	70
6	3. Mechanized hand equipment	62

As a first step, the first choice (hand) and the second choice (power equipment, remote hand control) can be selected. The difference between these two alternatives is only 5 points. With respect to the 106 points of the first choice, the difference is 5 per cent. The difference between the first choice and the third choice, however, is 106 minus 85 or 21 points. With respect to the 106 points of the first choice, this difference is 20 per cent. Thus, further concentration on the first two alternatives is justified.

To evaluate the above selection process, the reasons for the high scores of Level 1 and Level 6 can be identified from the determination

Result Step 2: Warehouse Type: 4
Activity: Item Picking
Result Step 3: Manual & Mech. (Manual, Mechanized, or Automated)

Date: 7/2/73 Analyst: A F vd M Plant: X

Factors \ Class / Level		Manual 1	2	3	4	Mech. 5	6	Automated 7	8	9	10
1. Shape/ Form of Handling Units	regular	⊗	⊗	⊗	⊗	⊗	⊗	x	x	x	x
	irregular	x	x	x	x	x	x				
2. Dimensions of Handling Units	small	⊗9	⊗2	⊗2	⊗5	⊗2	⊗2/3	x	x	x	x
	medium		x	x	x	x	x	x	x	x	x
	large			x		x	x				
3. Uniformity of Handling Units	1 fixed size	⊗1	⊗1	⊗1	⊗3	⊗3	⊗3	x	x	x	x
	variable sizes	x	x	x	x	x	x	x			
4. Weight of Handling Units	0-50 pounds	⊗10	⊗1	⊗1	⊗1	x	0/1	x	x	x	x
	50-1,000 pounds		x	x	x	x	x	x	x	x	x
	1,000-10,000 pounds					x	x	x	x	x	x
	over 10,000 pounds						x				
5. Fragility of Material	fragile	⊗8/4	⊗3	⊗3		1 ⊗	0/1	x	x	x	x
6. Total Average Quantity	low	x	x	x	x						
	medium		⊗1	⊗1	⊗2	⊗3	⊗3	x			
	high				x	x	x	x	x	x	x

Figure 25. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 1 of 5).

7. Peak Quantities	high		⊗6	⊗5	⊗4	⊗7		⊗2	⊗1											
	low		x	x	x	x		x	x		x	x	x	x						
8. Seasonality	constant		x	x	x	x		x	x		x	x	x	x						
	season variations		x	x	x	x		x	x		x	x	x	x						
	high season variations		⊗6	⊗4	⊗4	⊗6		⊗2	⊗1											
9. Frequency Distribution	constant		x	x	x	x		x	x		x	x	x	x						
	variable		x	x	x	x		x	x		x	x	x	x						
	highly variable		⊗6/8	⊗5	⊗4	⊗7		x	x											
10. Area Involved	small	na	x	x	x	x		x			x	x	x	x						
	medium			x	x	x		x	x		x	x	x	x						
	large							x	x		x	x	x	x						
11. Complexity of Activity (Activities)	simple		x	x	x	x		x	x		x	x	x	x						
	complex		⊗10	⊗3	⊗1			⊗1	⊗1		x	x	x	x						
	very complex		x	x				x												
12. Path	simple		⊗1	⊗1	⊗1	⊗1		⊗1	⊗1		x	x	x	x						
	compound		x	x	x			x	x		x	x	x	x						
	complex		x	x	x			x				x	x	x						
13. Number of Origins and Number of Destinations	one or a few		x	x	x	x		x	x		x	x	x	x						
	many		⊗10	⊗5	⊗ 5			⊗2	⊗5		x	x	x	x						
14. Distance	short: under 100 ft.		⊗10	⊗5	⊗5	⊗5		⊗2	⊗2/5		x	x	x	x						
	medium: 100-300 feet			x	x	x		x	x		x	x	x	x						
	long: over 300 feet							x	x		x	x	x	x						
15. Cross Traffic	much cross traffic		x	x	x			x	x		x	x	x	x						
	not much cross traffic		⊗1	⊗1	⊗1	⊗1		⊗3	⊗1		x	x	x	x						
16. Aisle Width	narrow: under 6 ft.		⊗10	⊗10	⊗10	x5		⊗7	⊗5		x	x	x	x						
	wide: over 6 feet		x	x	x	x		x	x		x	x	x	x						

Figure 25. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 2 of 5).

17.	Ceiling Height/ Clear Height	low: under 12 feet	x	x	x	x	x		x	x	x	x		
		medium: 12-20 ft.	⊗1	⊗1	⊗1	⊗1	⊗1	⊗1	x	x	x	x		
		high: over 20 feet					x	x	x	x	x	x		
18.	Column Spacing	small: less than 15 feet	x	x	x	x	x		depends on type of					
		medium: 15-30 feet	⊗1	⊗1	⊗1	⊗1	x	⊗1	equipment					
		large: over 30 feet	x	x	x	x	x	x						
19.	Column Load Capacity	low: less than 2,000 pounds	x	x	x	x	x		depends					
		medium: 2,000-10,000 pounds	x	x	x	x	x	x	on type of					
		high: over 10,000 pounds	⊗1	⊗1	⊗1	x1	⊗1	⊗1	equipment					
20.	Floor-Running Surface	smooth		⊗1			⊗1		depends on					
		not important	x		x	x		x	type of equipment					
21.	Likelihood of Change of Product or Product Mix	stable	⊗1	⊗1	⊗1	⊗2	⊗3	⊗5/4	x	x	x	x		
		change within 5 years	x	x	x	x	x							
		change within 1 year	x	x	x	x								
22.	Record-Keeping System/ Information System	not computerized	x	x	x	x	x	x	x					
		computerized							x	x	x	x		
23.	Total Storage Space	small	x	x	x	x	x	x						
		medium	⊗1	⊗1	⊗1	⊗2	⊗2	⊗2	x					
		large					x	x	x	x	x	x		
24.	Number of Line Items Stored	1-200	x	x	x	x	x	x						
		200-3,000	x	x	x	x	x	x						
		3,000-10,000					⊗2	⊗2	x	x				
		over 10,000						x	x	x	x	x		

Figure 25. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 3 of 5).

25.	Future Expansion	yes					⊗2	⊗2	x	x	x	x			
		no	x	x	x	x	x	x	x						
26.	General Economic Conditions	favorable					⊗2	⊗2	x	x	x	x			
		unfavorable	x	x	x	x									
27.	Growth Potential and Trends	high					x	x	x	x	x	x			
		normal	⊗1	⊗1	⊗1	⊗2	⊗2	⊗2	x						
		low	x	x	x	x									
28.	Competitors' Activities	Level 1	⊗5	⊗4											
		Level 2	x	x	x										
		Level 3		x	x	x									
		Level 4			x	x	x								
		Level 5				x	x	x							
		Level 6					x	x	x						
		Level 7						x	x	x					
		Level 8							x	x	x				
		Level 9								x	x	x			
		Level 10									x	x			
29.	Physical Requirements and Fatigue	low				⊗8	⊗6	⊗10	x	x	x	x			
		medium		⊗2	⊗2										
		high	x	x											
30.	Skill Required	low	x	x	x	x									
		medium					⊗5	⊗6/5							
		high							x	x	x	x			
31.	Wages	low	x	x	x	x	x	x							
		medium					x	x	x	x					
		high					⊗6	⊗10	x	x	x	x			
32.	Employees' Attitude towards Mechanization/ Automation	negative													
		indifferent		x	x	x	x	x							
		positive		⊗1	⊗2	⊗5	⊗5	⊗5							

Figure 25. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 4 of 5).

33.	Managers' Attitude towards Mechanization/ Automation	negative													
		indifferent			⊗1	⊗2	⊗3	⊗3	⊗5	x					
		positive			x	x	x	x	x	x	x	x	x	x	
34.	Noise Produced	high							x						
		low	⊗5	⊗5	⊗3	⊗5		⊗3	⊗5	x	x	x	x		
35.	Monotony of Job	monotonous	x	x	x					x	x	x	x		
		not monotonous	⊗2	⊗2	⊗2	⊗5		⊗3	x6	x	x	x	x		
36.	Financial Policy	spend/invest						⊗1	⊗1	x	x	x	x		
		save on investments	x	x	x	x									
37.	Labor Market	easy to get labor	x	x	x										
		difficult to get labor		⊗1	⊗2	⊗7		⊗7	x10	x	x	x	x		

Total Number of Check Marks	23	29	27	23	31	30		
Total Score after Grading	106	70	62	85	84	101		
Total Score after Regrading	104					105		

Figure 25. Determination Sheet for the Selection of the Level of Mechanization/Automation (page 5 of 5).

sheet.

The most important arguments that caused the high score for Alternative 1 (hand) are:

Factor 2. Dimensions of handling units are quite suitable for manual handling.

Factor 4. Weight of handling units are quite suitable for manual handling.

Factor 5. Fragility of material is a reason for manual handling.

Factor 8. High seasonal variations cause poor utilization of expensive mechanized equipment.

Factor 9. Frequency distribution over day and week (highly variable) causes poor utilization of expensive equipment.

Factor 11. Complexity of activity. Item picking of records is classically suited to manual operations.

Factor 13. Number of origins and number of destinations. Picking takes place at many places. This is a major obstacle to mechanization.

Factor 14. Distance. The short distance is quite suitable for manual handling.

Factor 16. Aisle width. Manual picking can be done in narrow aisles.

Factor 28. Competitor picks manually.

The most important arguments that caused the high score for Level 6 are:

Factor 29. Physical requirements and fatigue. Remote hand-controlled equipment does not require much physical effort and does not cause much fatigue.

Factor 31. Wages. Existing labor wages can be classified as high.

Factor 37. Labor market. It is difficult to hire labor.

Having identified these arguments, the analyst might want to make a few changes in the grades on the determination sheet. These second grades are placed in the sheet behind the first grades. (The two numbers are separated by a slash (/) sign.) This regrading process leads to the following final score:

1. Level 6.	Power equipment, remote hand control	105 points
2. Level 1.	Hand	104 points.

It is obvious from this result that the decision in Step 3 to carry over both classes, manual and mechanized, was a good decision.

Conclusion. Even after regrading, no selection can be made between Level 6 and Level 1. This means that equipment alternatives from both Level 6 and Level 1 must be considered in the next step of the procedure.

7-2-5. Step 5. Select the Specific Type of Equipment

Having selected two levels of mechanization/automation, the analyst can select the equipment alternatives from the Overviews of Equipment Alternatives (see Chapter V and Appendix B). For the activity "item picking," the following alternatives can be selected:

1. Level 1: Hand
   a. Hand
2. Level 6: Power equipment, remote hand control
   a. Overhead crane
   b. Conveyors, different types
   c. Hoists.

Obviously, an overhead crane or a hoist is not used for the picking of single gramophone records. Consequently, two serious alternatives are left:

1. Hand
2. Conveyor, remote hand control.

These two alternatives can be related to 68 relevant factors with the help of a Determination Sheet for the Selection of the Specific Type of Warehouse Equipment, as developed in Chapter V. This is done in Figure 26. Grades, as described in the previous two steps, also have been placed on this chart.

The results shown in Table 12 indicate that it is very difficult to make a choice without conducting a more detailed study of the particular situation. Several arguments in favor of both alternatives can be

Result Step 2: Warehouse Type No. _____
Activity or Activities: _____
Result Step 3: _____ (Manual, Mechanized, or Automated)
Result Step 4: Level of Mechanization/Automation _____
_____

Date: _____ Analyst: _____ Firm: _____

Factors \ Equipment Alternatives		1. Hand	2. Conveyor	
1. Type of Material	unit bulk liquid gas	x 0	x 0	
2. Shape/Form of Handling Units	regular irregular	x 1	x 3	
3. Dimensions of Handling Units	small medium large	x 5	x 2	
4. Uniformity of Handling Units	1 fixed size variable sizes	x 1	x 3	
5. Total Average Quantity	low medium high	x 4	x 6	
6. Number of Orders per Day	low: 1-100 medium: 100-300 high: over 300			
7. Quantity per Delivery (from supplier) per Item	less than 1 unit load more than 1 unit load	na	na	

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 1 of 7).

8. Quantity per Order per Item	less than 1 unit load more than 1 unit load	x 1	x 1
9. Peak Quantities	low: less than 2 x average quantity high: more than 2 x average quantity	x 6	x 4
10. External Factors		-	-
11. Stock Quantities per Item	low medium high	x 2	x 6
12. Order Delivery Time	short: less than 1 day long: more than 1 day	x 1	x 2
13. Competitor's Warehouse	Hand	x 5	
14. Weight of Handling Unit	under 50 pounds 50-1,000 pounds 1,000-10,000 pounds over 10,000 pounds	x 5	x 3
15. Area Involved	small medium large	x 1	x 3
16. Distance of Move	under 100 feet 100-300 feet over 300 feet	x 9	x 5
17. Frequency Distribution	no variability low variability high variability	x 6	x 4
18. Likelihood of Change of Product or Product Mix	stable change within 5 years change within 1 year	x 1	x 4

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 2 of 7).

19.	Present Information System/ Record-Keeping System	computerized not computerized			x	1	x	1
20.	Total Storage Space		small medium large		x	4	x	6
21.	Number of Line Items Stored	under 200 200-3,000 3,000-20,000 over 10,000			x	3	x	6
22.	Future Expansions		yes no some		x	2	x	4
23.	General Economic Conditions	favorable unfavorable			x	1	x	4
24.	Growth Potential and Trends	favorable constant unfavorable			x	1	x	3
25.	Wages	low medium high			x	1	x	9
26.	Employees' Attitude	negative indifferent positive					x	5
27.	Management's Attitude	negative indifferent positive			x	1	x	1

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 3 of 7).

28. Comfort and Fatigue	good situation bad situation reasonable	x 2	x 8	
29. Monotony of Job	monotonous not monotonous	x 1	x 2	
30. Financial Policy	investment/spending save	x 1	x 3	
31. Labor Market	favorable unfavorable		x 8	
32. Fragility of Material	fragile	x 4	x 1	
33. Seasonality	constant quantity variable quantities highly variable quantities	x 6	x 3	
34. Complexity of Activity (Activities)	simple complex very complex	x 6	x 4	
35. Path	simple compound complex	x 6	x 4	
36. Number of Origins and Number of Destinations	one or a few many	x 9	x 1	
37. Cross Traffic	much not much some	x 4	x 1	
38. Aisle Width	narrow: under 6 feet wide: over 6 feet	x 9	x 6	

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 4 of 7).

39. Ceiling Height/ Clear Height	low: under 12 feet medium: 12-20 feet high: over 20 feet	x 1	x 2	
40. Column Spacing	small: under 15 feet medium: 15-30 feet large: over 30 feet	x 1	x 1	
41. Column Load Capacity	low: under 2,000 lbs. medium: 2,000-10,000 lbs. high: over 10,000 lbs.	x 1	x 1	
42. Floor Running Surface	smooth rough	-	-	
43. Skill Required	low medium high	x 8	x 4	
44. Noise Produced	low noise level high noise level	x 1	x 1	
45. Levels of Route	1 2-5 over 5	x 6	x 3	
46. Sequence of Moves	fixed variable	x 5	x 6	
47. Dimensions of Building	small medium large	x 1	x 1	
48. Shape of Building	square rectangular other	x 1	x 1	

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 5 of 7).

49. Number of Floors	one	x 1	x 1	
	more than one			
50. Space Available for Equipment	small	x 9	x 1	
	medium			
	large			
51. Construction of Building	steel			
	concrete	x 1	x 1	
	other			
52. Legal Requirements	special measures			
	no special measures	x 1	x 1	
53. Number of Aisles	a few			
	many			
	to be determined	-	-	
54. Location of Aisles	fixed			
	to be determined	x 1	x 1	
55. Stacking Height	low: under 12 feet			
	medium: 12-20 feet	na	na	
	high: over 20 feet			
56. Floor Weight Limits	low: under 250 psi			
	medium: 250-1,000 psi	x 1	x 1	
	high: over 1,000 psi			
57. Ramps		to be designed		
58. Sales Unit of Product	can be handling unit	x 1	x 1	
	cannot be handling unit			
59. Package Characteristics	-package can be handling unit	x 1	x 1	
	-packages can be arranged into unit load			
	-package is difficult to handle			

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 6 of 7).

60. Shipping and Receiving Schedule			na	na	
61. Carrier Caracteristics			na	na	
62. Inventory Policy			na	na	
63. Motivation and Satisfaction		low normal high	x 1	x 5	
64. Heat Produced	unacceptable acceptable		x 1	x 1	
65. Injuries	safe dangerous		x 1	x 3	
66. Union Attitude	positive indifferent negative		x 1	x 1	
67. Labor Legislation	many obligations / restrictions not many obligations / restrictions		x 1	x 1	
68. Safety Laws		yes	x 1	x 1	
Total Number of Check Marks			56	57	
Total Score			157	166	

Figure 26. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 7 of 7).

identified.

Table 12. A Summary of Two Selected Alternatives

Alternative	Number of Cross Marks	Total Score
Hand	56	157
Conveyor, remote hand control	57	166

Those in favor of hand picking are:

Factors 3 and 14	Dimensions and weights of handling units are quite suitable for manual picking.
Factors 9, 17, and 33	High peak quantities, highly variable frequency distribution, and widely seasonal variations cause poor utilization of expensive conveyor equipment.
Factor 13	Competitor uses hand picking.
Factors 16, 34, and 45	Picking activity is quite suitable for doing by hand (distance, complexity, levels).
Factor 36	Picking takes place at a large number of locations.
Factor 37	No problems with cross traffic (replenishing).
Factor 50	In storage areas not much space is available for equipment (aisle width).

Factor 43. Requires low skills

Arguments favoring the use of conveyor equipment are:

Factors 2 and 4. Units are suitable for conveyor-release picking (regular shape, one fixed size).

Factor 5. Total average quantity can be classified as medium.

Factor 18. Product is not likely to change within five years.

Factors 20 and 21. The size of the warehouse (total storage space, number of items stored) can be classified as medium.

Factor 22, 23 and 24. Future expectations (expansion, general economic trends, etc.) are not unfavorable.

Factors 28 and 65. Low comfort and fatigue, more comfort, less injuries, etc.

Factor 31. It is very difficult to obtain labor.

Factor 25. Existing wages are high.

Factor 26. Employees' attitude is positive.

Factor 63. Expected to raise motivation/satisfaction.

A decision cannot be made solely on the basis of the above arguments. Consequently, this step, as is the result of the pre-selection stage of the equipment selection procedure, consists of two alternatives:

- Hand picking

- Conveyor, remote hand control item release.

Conclusion. Because item picking is done by hand in the existing situation, the advice would be to design a warehouse featuring item picking by means of remote hand-controlled conveyor and to compare this design with the existing situation.

CHAPTER VIII

A METHOD FOR THE DETERMINATION OF THE APPLICABILITY OF A PARTICULAR PIECE OF WAREHOUSE EQUIPMENT

In Chapter V, a method of selecting the appropriate warehouse equipment for a particular warehouse situation was developed. With slight modifications this method can be used to determine what kinds of warehouse situations are suitable for a specific piece of equipment. This procedure is outlined below according to a format that is a simplified version of the method presented in Chapter V:

Step 1. Identify all of the relevant factors.

Step 2. Determine the applicability of the appropriate warehouse type(s).

Step 3. Determine the applicability of the piece of equipment to be considered. (This step includes the class and the level of mechanization/automation of the equipment.)

8-1. Step 1. Identify All of the Relevant Factors

Since equipment selection can be described as the determination of the physical and economic applicability of different equipment alternatives, the factors identified in Chapter V, Step 1, are relevant to the problem of the determination of the applicability of a certain type of warehouse equipment.

8-2. Step 2. Determine the Applicability of the Appropriate Warehouse Type(s)

Not every type of warehouse equipment is applicable in every warehouse type. The basic reason for this is that some types of equipment have been designed to handle unit loads (pallets, bins), but some types of warehouses do not store items in unit loads. For example, a forklift truck cannot be used in a warehouse situation in a storage area where single packages are brought in and single packages are taken out.

The purpose of this step in the procedure is to eliminate those warehouse types that are not suitable for the application of the piece of equipment under consideration. This can be done with the help of the Determination Sheet for the Selection of the Warehouse Type. The result is a preliminary list of characteristics that favor the applicability of the piece of equipment to be considered. An illustrative application is given in Chapter IX, Section 9-2.

8-3. Step 3. Determine the Applicability of the Piece of Equipment To Be Considered

8-3-1. Step 3a. Determine the Applicability of the Appropriate Class of Mechanization/Automation

Any piece of equipment under study, of course, will belong to one of the three classes of mechanization/automation. With the help of the Determination Sheet for the Selection of the Class of Mechanization/Automation, as developed in Chapter V, Step 3, the factors that deter-

mine the applicability of the appropriate class can be identified.

8-3-2. Step 3b. Determine the Applicability of the Appropriate Level of Mechanization/Automation

A particular piece of equipment also will fall into a specific level of mechanization/automation. With the help of the Determination Sheet for the Selection of the Level of Mechanization/Automation, as developed in Chapter V, Step 4, the factors that determine the applicability of the appropriate level may be identified.

8-3-3. Step 3c. Determine the Applicability of the Piece of Equipment To Be Considered

With the help of the Determination Sheet for the Selection of the Specific Type of Warehouse Equipment, as developed in Chapter V, Step 5, the factors that determine the applicability of the particular piece of equipment can be identified. From this list the characteristics of a situation that is suitable for the application of this specific piece of equipment can be derived.

Since the Determination Sheet for the Selection of the Specific Type of Warehouse Equipment includes all of the factors of both the Determination Sheet for the Selection of the Class of Mechanization/Automation and the Determination Sheet for the Selection of the Level of Mechanization/Automation, Steps 3a, 3b, and 3c can be combined into one Step 3. In Step 3 the Determination Sheet for the Selection of the Specific Type of Warehouse Equipment is used to identify the factors that determine the applicability of the piece of equipment (includ-

ing its class and its level of mechanization). After these factors have been identified, their specific values--which may be indicated on the chart--become characteristics of warehouse situations that are suitable for the application of the equipment under consideration.

CHAPTER IX

THE DETERMINATION OF THE APPLICABILITY OF AN AUTOMATED STACKER CRANE

9-1. Introduction

The purpose of this chapter is to provide an illustration of the method described in Chapter VII by investigating the situations in which an automated, computer-controlled stacker crane is an appropriate piece of warehouse equipment.

The stacker crane has caused many changes in the field of warehouses. It has made it possible to go to large storage heights (over 90 feet (9)) and to introduce high levels of automation (computer-controlled moves in the storage areas without any human handling (15)). For these reasons, the stacker crane has received much attention.

From the point of view of the warehouse manager, the stacker crane is an interesting equipment alternative for an important part of his warehouse operations. Whether this alternative is the most appropriate can be determined with the help of the equipment selection method developed in Chapter V.

From the point of view of the equipment manufacturer, it is important to know in what kind of warehouses the stacker crane is applicable. For this purpose, the method described in Chapter VIII can be

used.

The investigation is described in the following section.

9-2. The Procedure Applied

9-2-1. Step 1. Identify All of the Relevant Factors

The factors relevant to the problem of the determination of the applicability of a stacker crane are the same as the factors relevant to the problem of the selection of warehouse equipment, as presented in Chapter V, Section 5-2.

9-2-2. Step 2. Determine the Applicability of the Appropriate Warehouse Type(s)

The stacker crane has been designed to handle unit loads (pallets or bins). For this reason, the appropriate warehouse types are Type 2, Type 3, Type 5, Type 6, and Type 7 (see Table 1).

The characteristics of situations in which these warehouse types are appropriate can be identified with the help of the Determination Sheet for the Selection of the Warehouse Type, as developed in Chapter V, Section 5-3. This chart is shown in Figure 27, and from it the following characteristics can be identified:

1. Type of material. This study is limited to unit materials (packages, etc.).
2. Shape or form of handling unit should be regular.
3. Dimensions of handling unit should not be small (at least a pallet size of 24 inches x 32 inches, as far as the units to be handled by the stacker crane are concerned).

Date: 7/5/73 Analyst: A F vd M Firm: Any

Factors \ Warehouse Types			1	2	3	4	5	6	7
1. Type of Material		unit	x	x	x	x	x	x	x
		bulk	-	-	-	-	-	-	-
		gas	-	-	-	-	-	-	-
		liquid	-	-	-	-	-	-	-
2. Shape/Form of Handling Units	Flow 1[1]	regular	x	x	x	x	x	x	x
		irregular	x			x			
	Flow 2[1]	regular	x	x	x	x	x	x	x
		irregular	x	x		x	x	x	
	Flow 3[1]	regular	-	-	-	x	x	x	x
		irregular	-	-	-	x	x		
3. Dimensions of Handling Units	Flow 1	small	x			x			
		medium	x	x	x	x	x	x	x
		large		x	x		x	x	x
	Flow 2	small	x	x		x	x	x	
		medium	x	x	x	x	x	x	x
		large			x				x
	Flow 3	small	-	-	-	x	x	x	
		medium	-	-	-	x	x	x	x
		large	-	-	-			x	x
4. Uniformity of Handling Units	Flow 1	1 fixed size	x	x	x	x	x	x	x
		variable sizes	x			x			
	Flow 2	1 fixed size	x	x	x	x	x	x	x
		variable sizes	x	x		x	x	x	
	Flow 3	1 fixed size	-	-	-	x	x	x	x
		variable sizes	-	-	-	x	x		
5. Total Average Quantity		low	x	x		x	x		
		medium	x	x	x	x	x	x	
		high			x			x	x
6. Quantity per Delivery (from supplier) per Item	less than 1 unit load		x			x			
	more than 1 unit load			x	x		x	x	x

Figure 27. Determination Sheet for the Selection of the Warehouse Type (page 1 of 2).

7. Quantity per Order per Item	less than 1 unit load	x	x		x	x	x	
	more than 1 unit load			x				x
8. Peak Quantities	low: less than 2 x average quantity	x	x	x				
	high: more than 2 x average quantity				x	x	x	x
9. External Factors	9a							
	9b							
10. Stock Quantities per Item (average)	low	x	x	x				
	medium	x	x	x	x	x	x	x
	high			x	x	x	x	x
11. No. of Orders per Day	low: 1-100	x	x	x				
	medium: 100-300				x	x	x	x
	high: over 300				x	x	x	x
12. Required Order Delivery Time (service degree)	short: less than 1 day			x	x	x	x	x
	long: more than 1 day	x	x					
13. Competitor's Warehouse	Type 1	x						
	Type 2		x					
	Type 3			x				
	Type 4				x			
	Type 5					x		
	Type 6						x	
	Type 7							x
TOTAL								

[1] See Figure 4.

Figure 27. Determination Sheet for the Selection of the Warehouse Type (page 2 of 2).

4. Uniformity of handling units. Should be one fixed size, at least in length and width dimensions (standard handling unit equals unit load). The height can vary within certain limits.

5. Total average quantity can be low, as far as the type of warehouse is concerned; however, at least medium is preferred.

6. Quantity per delivery (from supplier) per item. Should be more than one unit load in quantity to make it possible to form unit loads, if the supplier did not already do so.

7. Required order delivery time. In most cases, this parameter should be short.

8. Competitor's warehouse. If the competition uses a warehouse type that is suitable for the application of a stacker crane (Types 2, 3, 5, 6, and 7), adoption of a similar situation may be indicated.

9-2-3. Step 3. Determine the Applicability of the Automated Stacker Crane

The characteristics of a situation in which a particular piece of equipment is applicable can be identified with the help of a Determination Sheet for the Selection of a Specific Type of Warehouse Equipment, as developed in Chapter 5, Section 5-6. This is shown in Figure 28. The following list of characteristics can be composed from this sheet, combined with the results of Step 2:

1. Type of material. Unit-type materials (packages, individual items, etc.) are the materials for which a stacker crane is to be considered as a piece of handling equipment.

2. Shape/form of handling units. The shape and/or form of the handling units should be regular, at least within certain limits.

3. Dimensions of handling units. The dimensions of the handling units should not be small. As a minimum size, the smallest pallet size meeting ASME standards can be used: 24 inches x 32 inches. A more commonly used size is 40 inches x 48 inches (7). Oblong handling units can be used, such as the bin for the storage

Result Step 2: Warehouse Type No. _____
Activity or Activities: _____
Result Step 3: _____ (Manual, Mechanized, or Automated)
Result Step 4: Level of Mechanization/Automation _____
_____

Date: _____ Analyst: _____ Firm: _____

Factors	Equipment Alternatives	1. Automated Stacker Crane		
1. Type of Material	unit	x		
	bulk			
	liquid			
	gas			
2. Shape/Form of Handling Units	regular	x		
	irregular			
3. Dimensions of Handling Units	small			
	medium	x		
	large			
4. Uniformity of Handling Units	1 fixed size	x	at least in 2 dimensions	
	variable sizes			
5. Total Average Quantity	low			
	medium			
	high	x		
6. Number of Orders per Day	low: 1-100			
	medium: 100-300	x		
	high: over 300	x		
7. Quantity per Delivery (from supplier) per Item	less than 1 unit load			
	more than 1 unit load	x		

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 1 of 7).

8. Quantity per Order per Item	less than 1 unit load	x		
	more than 1 unit load	x		
9. Peak Quantities	low: less than 2 x average quantity			
	high: more than 2 x average quantity			
10. External Factors		not applicable		
11. Stock Quantities per Item	low			
	medium	x		
	high	x		
12. Order Delivery Time	short: less than 1 day			
	long: more than 1 day			
13. Competitor's Warehouse	stacker crane	x		
	no stacker crane			
14. Weight of Handling Unit	under 50 pounds			
	50-1,000 pounds	x		
	1,000-10,000 pounds	x		
	over 10,000 pounds			
15. Area Involved	small			
	medium	x		
	large	x		
16. Distance of Move	under 100 feet	x		
	100-300 feet	x		
	over 300 feet	x		
17. Frequency Distribution	no variability	x		
	low variability			
	high variability			
18. Likelihood of Change of Product or Product Mix	stable	x		
	change within 5 years			
	change within 1 year			

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 2 of 7).

19.	Present Information System/ Record Keeping System	computerized		x	
		not computerized			
20.	Total Storage Space		small		
			medium		
			large	x	
21.	Number of Line Items Stored	under 200			
		200-3,000			
		3,000-20,000		x	
		over 10,000		x	
22.	Future Expansions		yes	x	
			no		
23.	General Economic Conditions	favorable		x	
		unfavorable			
24.	Growth Potential and Trends	favorable		x	
		constant		x	
		unfavorable			
25.	Wages	low			
		medium			
		high		x	
26.	Employees' Attitude	negative			
		indifferent		x	
		positive		x	
27.	Management's Attitude	negative			
		indifferent			
		positive		x	

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 3 of 7).

28.	Comfort and Fatigue	good situation bad situation	x	
29.	Monotony of Job	monotonous not monotonous	x	
30.	Financial Policy	investment/spending save	x	
31.	Labor Market	favorable unfavorable	x	
32.	Fragility of Material	fragile	no restrictions	
33.	Seasonality	constant quantity variable quantities highly variable quantities		
34.	Complexity of Activity (Activities)	simple complex very complex	not applicable	
35.	Path	simple compound complex	not applicable	
36.	Number of Origins and Number of Destinations	one or a few many	not applicable	
37.	Cross Traffic	allowed not allowed	x	
38.	Aisle Width	narrow: under 6 feet wide: over 6 feet	x	

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 4 of 7).

39.	Ceiling Height/ Clear Height	low: under 12 feet			
		medium: 12-20 feet	x		
		high: over 20 feet	x		
40.	Column Spacing	small: under 15 feet			
		medium: 15-30 feet			
		large: over 30 feet			
41.	Column Load Capacity	low: under 2,000 lbs.			
		medium: 2,000-10,000 lbs.	x		
		high: over 10,000 lbs.	x		
42.	Floor Running Surface	smooth	x		
		rough			
43.	Skill Required	low	see labor market		
		medium			
		high			
44.	Noise Produced	low noise level	not applicable		
		high noise level			
45.	Levels of Route	1			
		2-5			
		over 5	x		
46.	Sequence of Moves	fixed	x		
		variable			
47.	Dimensions of Building	small			
		medium	x		
		large	x		
48.	Shape of Building	square	x		
		rectangular	x		
		other	see ceiling height		

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 5 of 7).

49.	Number of Floors	one	x		
		more than one			
50.	Space Available for Equipment	small	x		
		medium			
		large			
51.	Construction of Building	steel	x		
		concrete	x		
		other			
52.	Legal Requirements	special measures			
		no special measures	x		
53.	Number of Aisles	a few			
		many			
		to be determined	x		
54.	Location of Aisles	fixed			
		to be determined	x		
55.	Stacking Height	low: under 12 feet			
		medium: 12-20 feet	x		
		high: over 20 feet	x		
56.	Floor Weight Limits	low: under 250 psi			
		medium: 250-1,000 psi			
		high: over 1,000 psi	x		
57.	Ramps		not applicable		
58.	Sales Unit of Product	can be handling unit	x		
		cannot be handling unit	x		
59.	Package Characteristics	-package can be handling unit	x		
		-packages can be arranged into unit load	x		
		-package is difficult to handle			

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 6 of 7).

60. Shipping and Receiving Schedule			not applicable		
61. Carrier Caracteristics	suitable for unit loads		x		
62. Inventory Policy			not applicable		
63. Motivation and Satisfaction		low normal high	x		
64. Heat Produced	unacceptable acceptable		not applicable		
65. Injuries	safe dangerous		x		
66. Union Attitude	positive indifferent negative		x x		
67. Labor Legislation	many obligations/ restrictions not many obligations/ restrictions		x		
68. Safety Laws in Present Situation		severe	x		
					TOTAL

Figure 28. Determination Sheet for the Selection of the Specific Type of Warehouse Equipment (page 7 of 7).

and handling of steel bars and profiles: 12 feet x 2 feet x 2 feet (10).

4. Uniformity of handling units. The handling units of the warehouse should be limited to one or two sizes.

5. Total average quantity. In general the stacker crane is applicable when total quantities are high. A minimum limit could be 100,000 tons of material per year.

6. Number of orders per day. In general, a stacker crane is not applicable when the number of orders per day is low (less than 100). This factor has to be considered together with Factor 8.

7. Quantity per delivery (from supplier) per item. These quantities should be such that handling units with the characteristics described under Points 2, 3, 4, and 13 can be formed (if the supplier has not already done so). Handling units that have these characteristics are called unit loads. This means that the incoming quantity per item should be much greater than the quantity of one unit load.

8. Quantity per customer order per item. If the quantity per customer order per item is more than the quantity of one unit load, the customer order can be built up from unit loads, and the stacker crane can be used for item picking. This is a very positive argument for the applicability of a stacker crane.

9. Peak quantities, seasonal fluctuations, frequency distributions over day and week. Variations in these factors result in poor utilization of the expensive automated stacker crane. The more constant the work load, the more applicable the automated equipment.

10. Stock quantities per item. In general, a stacker crane is not used if the stock quantities per item are low.

11. Order delivery time. If a short order delivery time is required, a stacker crane can mean a very good solution.

12. Competition. If the competition uses automated stacker cranes in his warehouse, there might be good reasons for introducing this equipment. In other words, if the stacker crane is a commonly used piece of equipment in a certain branch of industry (e.g., washing powders), the warehouses that do not yet use a stacker crane are potential candidates for the introduction of this type of

equipment.

13. Weight of handling units. Although exceptions do exist and load capacities vary with crane size, this type of equipment is applicable in situations with unit weights up to 5 tons ($\pm$ 10,000 pounds).

14. Area involved. In general, stacker cranes are not used if the area involved is small.

15. Distance of moves. Since the stacker crane can move with considerable speeds (up to 500 feet per minute, see (9)), this type of equipment is more efficient than other types in long aisles. Long aisles, in general, also reduce the number of aisles and the number of cranes to be purchased. For these reasons, the introduction of stacker crane(s) usually means a rearrangement of the storage area into fewer (but longer) aisles.

    An indicator for the applicability of a stacker crane cannot be derived from this situation. A general indicator could be total storage space (see Point 18).

16. Likelihood of change of product. If there is a possibility that the product is going to change, it is not advisable to introduce expensive, new equipment.

17. Record-keeping system/information system. To introduce an automated stacker crane, it is necessary that the record-keeping system be computerized. This very often includes the computerization of the information system, to a certain degree.

18. Total storage space. In general, a stacker crane is applicable in large storage areas.

19. Number of items stored. In general, an automated stacker crane is not used if only a small number of items are stored.

20. Future expansions/growth potential/trends, for the particular industry. If these variables are favorable, this is an extra indicator that a stacker crane might be a good equipment alternative for a new future situation.

21. General economic conditions. Management, in general, is not willing to invest in automated warehouse equipment when the general economic conditions are not favorable.

22. Existing wages. If existing wages are high, the introduction of a stacker crane(s) might result in lower total handling costs.

23. Employees' attitude towards introduction of a stacker crane. A positive employee attitude (for example, because of favorable comments from colleagues, trade magazines and their union) can be an additional indicator that this equipment is applicable. On the other hand, a negative employee attitude is a serious disadvantage.

24. Management attitude towards stacker cranes. Management attitude has to be positive. Even if the introduction of stacker crane equipment is profitable, management has to be convinced completely.

25. Comfort and fatigue. If, in the present situation, the comfort levels are low and fatigue levels are high, a stacker crane might be a good solution to these problems.

26. Monotony of job. Stacker cranes can bring improvement in situations in which monotonous jobs exist.

27. Financial policy of the company. Since automated stacker cranes require a considerable investment, the company must be willing to invest in warehouse equipment.

28. Labor market. In situations in which it is difficult to obtain labor, a company is forced in the direction of automation. In Western Europe, unskilled labor has been imported from Spain, Italy, Turkey, Morocco, and other countries simply because unskilled labor was not available locally. The introduction of automated stacker crane equipment can make possible a considerable reduction of the labor force in a warehouse. Therefore, in a warehouse situation where there are difficulties in obtaining sufficient labor, the stacker crane might be a solution.

29. Space available for equipment/aisle width. Because of its special construction, a stacker crane requires relatively very little space. In many cases, the aisle width is determined by the width of the unit load and not by the width of the stacker crane. Consequently, in situations where wide aisles exist, the stacker crane might improve space utilization.

30. Ceiling height/clear height/stacking height. One of the most important advantages of the stacker crane is that it makes possible storage at great heights. Application in buildings with low heights (under 12 feet) is not advisable. If existing operations take place

in a high building with many mezzanine floors or badly utilized space "under the roof," the stacker crane could bring much improvement.

31. Column spacing. Application of a stacker crane in a building with column spacings of less than 15 feet is almost impossible. In general, columns always cause problems in a warehouse. This was one of the reasons for the development of the new type of warehouse building described under Point 38.

32. Column load capacities. This factor needs to be considered only if the crane has to be supported by the building construction. Usually this is not the case.

33. Running surface. An automated stacker crane requires a very smooth running surface when it is supported on the floor. On the other hand, the floor on which the racks are constructed generally has small surface tolerances. The introduction of a stacker crane very often requires some improvement of the existing floor.

34. Levels of route. This factor relates to an obvious point: The stacker crane is applicable only if the storage takes place in storage racks.

35. Sequence of moves. In a situation where it is difficult to perform moves in the right sequence, a computer-controlled stacker crane could be a good solution.

36. Dimensions of building. A stacker crane cannot be used in a small building.

37. Number of floors. The stacker crane makes it possible to handle materials at large heights. The presence of mezzanine floors between storage racks can be an indication that a stacker crane can improve handling. On the other hand, a stacker crane cannot be used in a building where the storage area is separated by one or more fixed (building) floors.

38. Construction of building. If the stacker crane is to be supported by the building construction, certain strength conditions must be fulfilled. However, crane types do exist that are supported by the floor and that are only guided on top. These guidance devices can be attached to the building or to the top of the racks.

In case a new warehouse is built, an interesting building construc-

tion has been developed. Here the building framework is formed by the storage racks. The stacker crane is supported on the floor and/or on the top of the racks. The walls of the building are simply curtain walls of modern sheet material attached to the outside of the rack construction.

In general, the construction of an existing building does not necessarily limit the applicability of a stacker crane.

39. Legalrequirements. The introduction of a stacker crane can improve a situation where many safety precautions have to be taken. On the other hand, the use of stacker cranes also requires certain safety measures (fire protection, etc.).

40. Location of aisles. From the explanation under Point 15, it follows that the introduction of a stacker crane is difficult in a situation where the location of the aisles is fixed.

41. Floor weight limits. If a stacker crane is introduced in a situation where storage in racks takes place, this factor has already been taken into account. If, as a result of the introduction of the stacker crane, the storage height becomes greater (for example, to obtain better space utilization, shorter horizontal travel distances, etc.), this becomes an important factor. In general, storage suitable for the application of stacker cranes cannot take place on floors with a low floor-load capacity (unless the material stored is very light).

42. Sales unit of product. If the sales unit can be used as a unit load, this is a favorable situation for the applicability of a stacker crane. A tendency in the reverse direction can be noted in many branches of industry. In a supermarket pallet loads of soap powder can be seen. The unit load has been made a sales unit as far as sales from wholesaler to supermarket are concerned. Another example is the storage of an automobile engine on a pallet.

43. Packagecharacteristics. To form a unit load, it is necessary to have packages that can be arranged into unit loads.

44. Carrier characteristics. In designing a unit load to be handled by a stacker crane, carrier characteristics have to be taken into account.

45. Motivation and satisfaction. If, in the present situation, motivation and satisfaction are low, the introduction of stacker crane equipment might result in improvement (responsibility for expen-

sive machinery, pride in installation).

46. Injuries. The introduction of stacker crane equipment can result in a significant reduction in the number of injuries in a warehouse. If the number of injuries is high in a particular situation, this might be another favorable argument.

47. Union attitude. The attitude of labor unions towards automation can be an important influence on employees' attitudes as well as management attitudes. If the union attitude is positive, this can be an argument in favor of the introduction of automated stacker cranes.

48. Labor legislation and safety laws. Indirect labor costs due to labor legislation and safety laws can cause a considerable increase in warehousing costs. If this situation exists, the introduction of stacker crane equipment might cause a reduction of these costs.

This list can help to identify situations where the stacker crane is an appropriate piece of equipment.

CHAPTER X

SUMMARY AND RECOMMENDATIONS

10-1. Summary

The research can be summarized as follows:

1. The basic reasons for materials storage are:

   a. Differences in capacities (production capacities, transportation capacities).

   b. Differences in frequency distributions for successive flows of material.

   Consequently, materials storage can be reduced by:

   a. Adjusting capacities to frequency distributions.

   b. Adjusting frequency distributions to capacity.

   c. Adjusting capacities to capacities.

   d. Adjusting frequency distributions to frequency distributions.

   It is emphasized that the analyst should look into the possibilities for reducing materials storage before starting to design materials storage facilities.

2. Existing warehouse situations can be classified in accordance with the type of warehouse. Seven warehouse types have been distinguished, as shown in Figure 4.

3. A process chart has been designed for a general warehouse

situation. This chart is shown in Figure 5.

4. A warehouse can be looked upon as a system. With the help of the process chart mentioned in Point 3, the system of a general warehouse has been subdivided into eight sub-systems (receiving, transport to bulk storage, bulk storage, transport to picking storage, picking storage, order collecting, packing, and shipping). Each sub-system has been divided further into one or more modules. A summary is given in Table 5.
5. Charts have been developed to show for each module the equipment alternatives in the order of their level of mechanization. These Overviews of Equipment Alternatives are shown in Appendix B.
6. A method is presented for the selection of warehouse equipment. This method enables the analyst to make a selection from a wide variety of equipment alternatives. The method consists of five steps. For each of Steps 2 to 5, a chart has been designed that can help the analyst in making his decisions. These Determination Sheets are presented in Chapter V and are combined into one master chart in Appendix G so that an overview of the method may be obtained.
7. The above method is applied to an existing warehouse situation. This results in advice to design a remote hand-controlled

conveyor system for their item picking activity in order to make a detailed comparison with their present situation (which operates manually).

8. A method is presented to determine the applicability of a particular piece of warehouse equipment. The purpose of this method is to identify the characteristics of any situation in which a particular piece of equipment is applicable. The method consists of three steps, and the determination sheets of Steps 2 and 5 of the equipment selection method (see Point 6 above) can be used.
9. The method to determine the applicability of a particular piece of equipment has been applied to determine the characteristics of any situation in which an automated (computer-controlled) stacker crane is appropriate. This results in a list of 48 such characteristics.

10-2. Recommendations

1. The main disadvantage of the method for the selection of warehouse equipment is its complexity. This is caused by the large number of factors that are involved. For this reason, computerization of the method is recommended. The ideal situation would be that the analyst have a direct "conversation" with the computer. The computer could ask the

analyst the right questions (for example: Is Factor X an argument in favor of Alternative A?), give the right instructions (for example: Give a grade for the importance of Argument A), place the check marks, accumulate the grades, compute the final score for each alternative, make a choice and present the alternatives in order of preference, including the main reasons for that particular ranking.

2. The selection of warehouse equipment can be done in more detail by adding another step: Make a choice between conveyors, industrial vehicles, and cranes and hoists. However, this addition is recommended only if the number of equipment alternatives is very large.
3. Compared to the methods for equipment selection as presented by Bazaraa (5) and Pascual (12), the method presented here is more extensive:
   a. Many factors are taken into account (up to 68 factors).
   b. The method consists of many decision steps (five steps).

   The effectiveness of the three methods can be evaluated by applying them to the same (real-world) problem and comparing the results.
4. Further research can be done to find the trade-off between:
   a. The degree of accuracy of the method (the number of factors to take into account, the number of decision steps to take) and consequently, the quality of the final decision,

and

b. The time involved in the decision process and the complexity of the method.

APPENDIX A

PROCESS CHARTS OF THREE COMMON WAREHOUSES

APPENDIX A

PROCESS CHARTS OF THREE COMMON WAREHOUSES

Main Characteristics of Three Warehouse Situations

Warehouse 1:

a. No unit loads; packages are handled manually.

b. Bulk storage area and picking storage area.

c. Item picking is performed manually.

d. Incoming loads consist of several line items.

Warehouse 2:

a. Items are delivered in the form of unit loads (pallet loads, refrigerators, etc.). There is only one line item per unit load.

b. Unit loads are unloaded by forklift truck.

c. Transport to the bulk storage area is by roller conveyor.

d. Stacker cranes operate in the bulk storage area.

e. Transport from the bulk storage area to the picking storage area is by roller conveyor.

f. Picking storage consists of flow racks (live storage) on one level.

g. Unit loads, making up an order, are released in the right sequence by the flow rack system. Order accumulation takes place on a roller conveyor between the picking storage area and the packing (and checking, strapping, labeling) area.

h. Transport from the packing area to the shipping area is by roller conveyor.

i. Handling in the shipping area and loading is by forklift truck.

Warehouse 3:

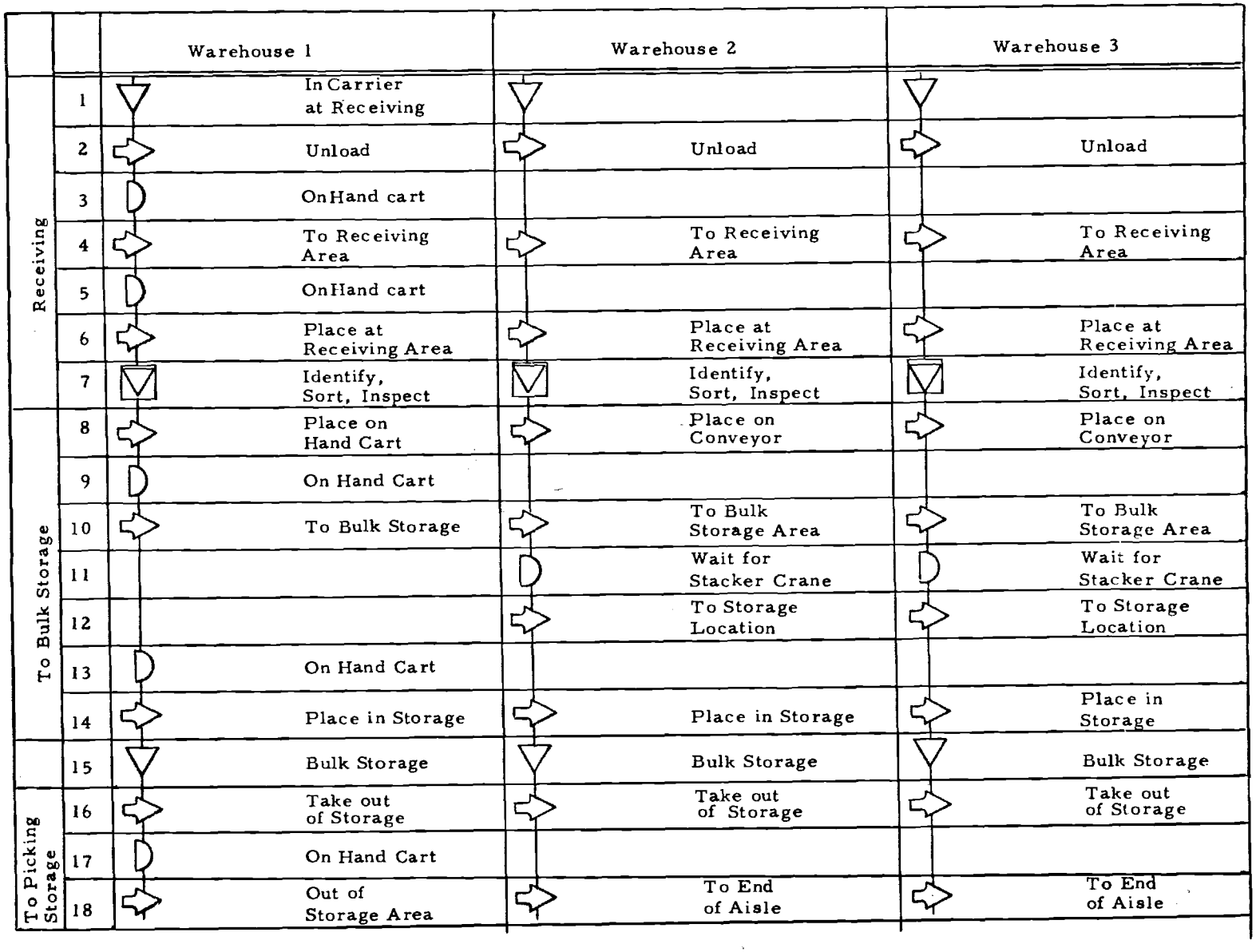
The conditions for Warehouse 2 apply, with the following exceptions:

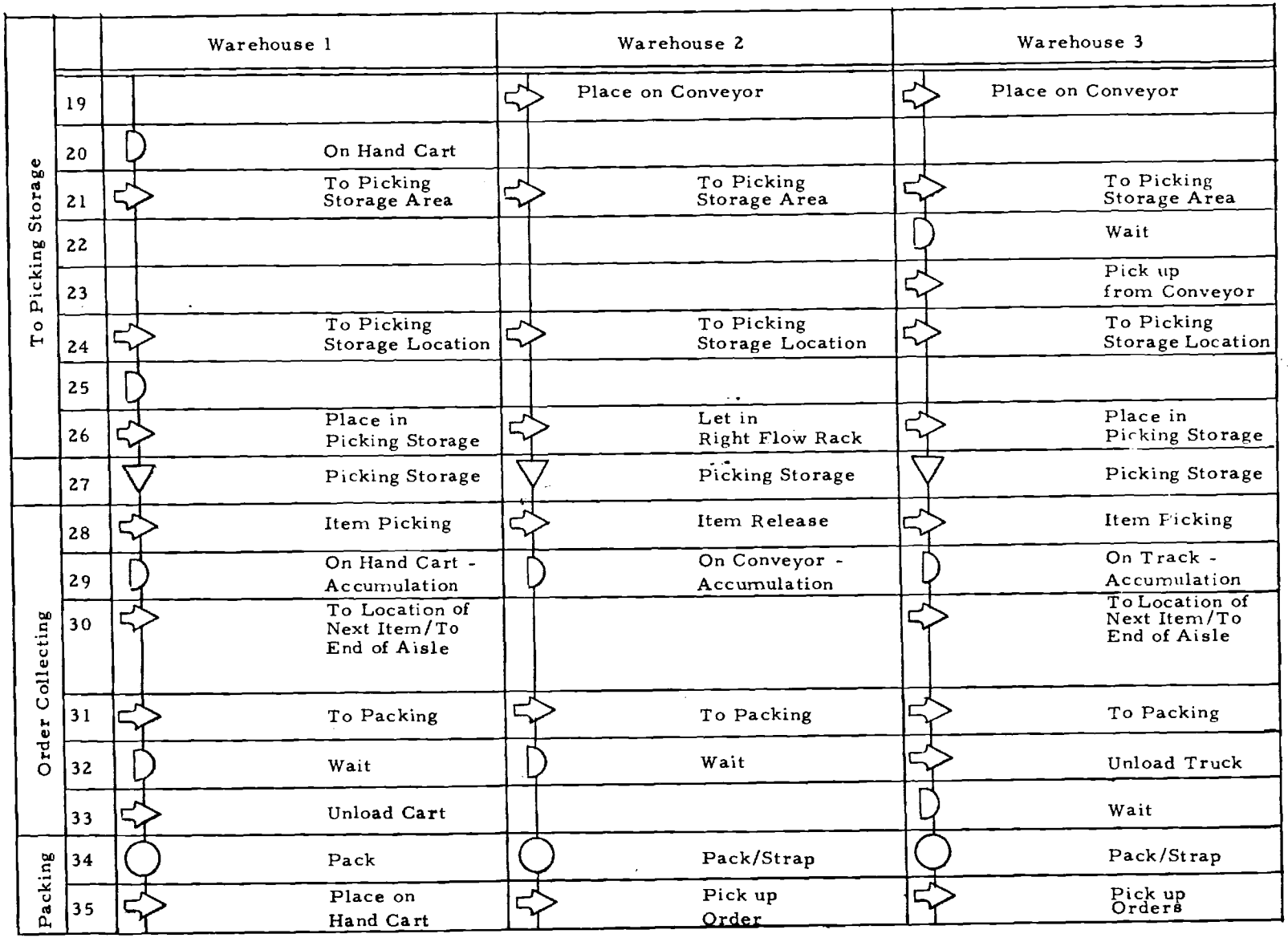
a. Orders are not built up from unit loads but from individual packages.

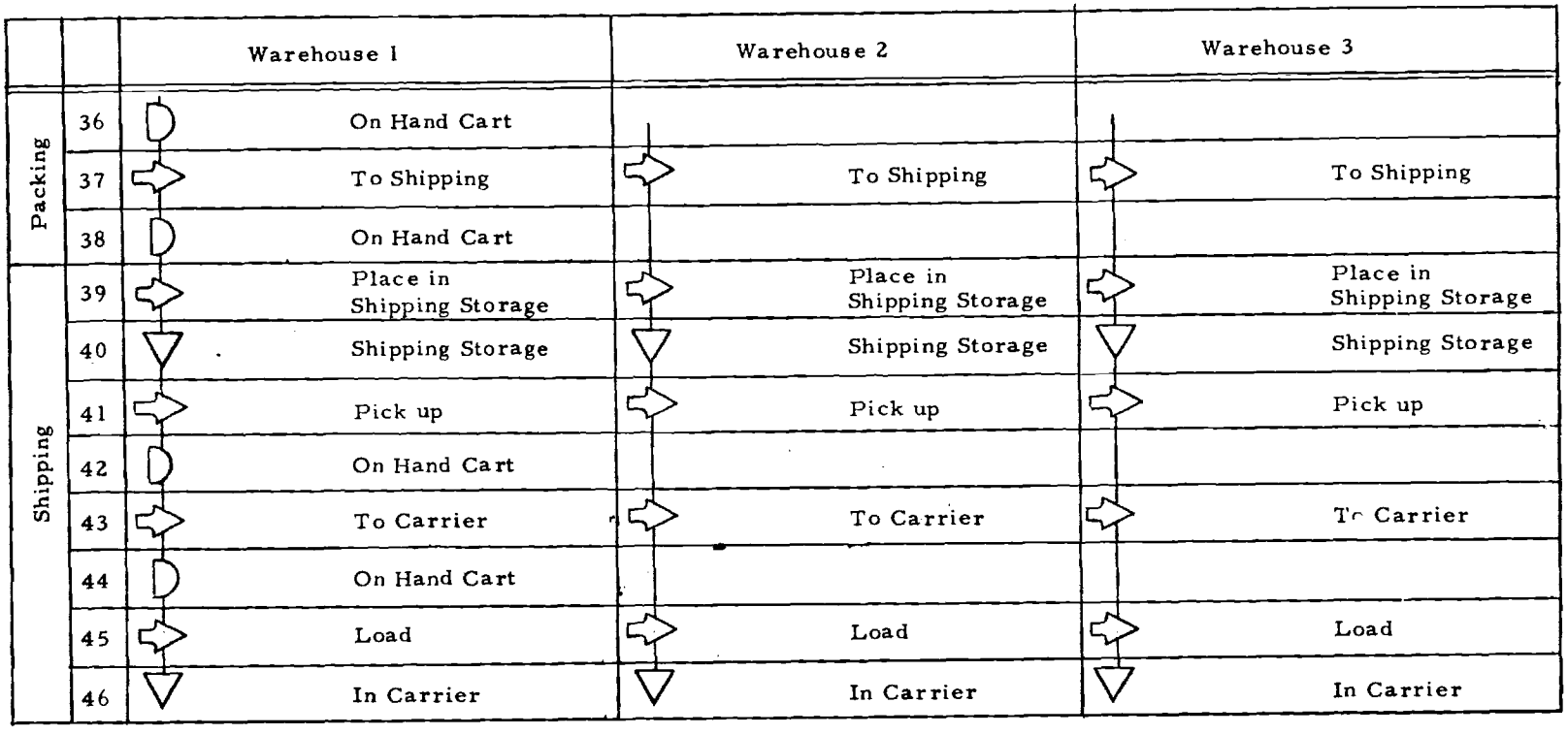
b. In the picking storage area, pallet loads (one line item per pallet) are stored on the floor. No racks, no flow racks. Order collecting is by powered hand truck (also order accumulation); item picking is done manually.

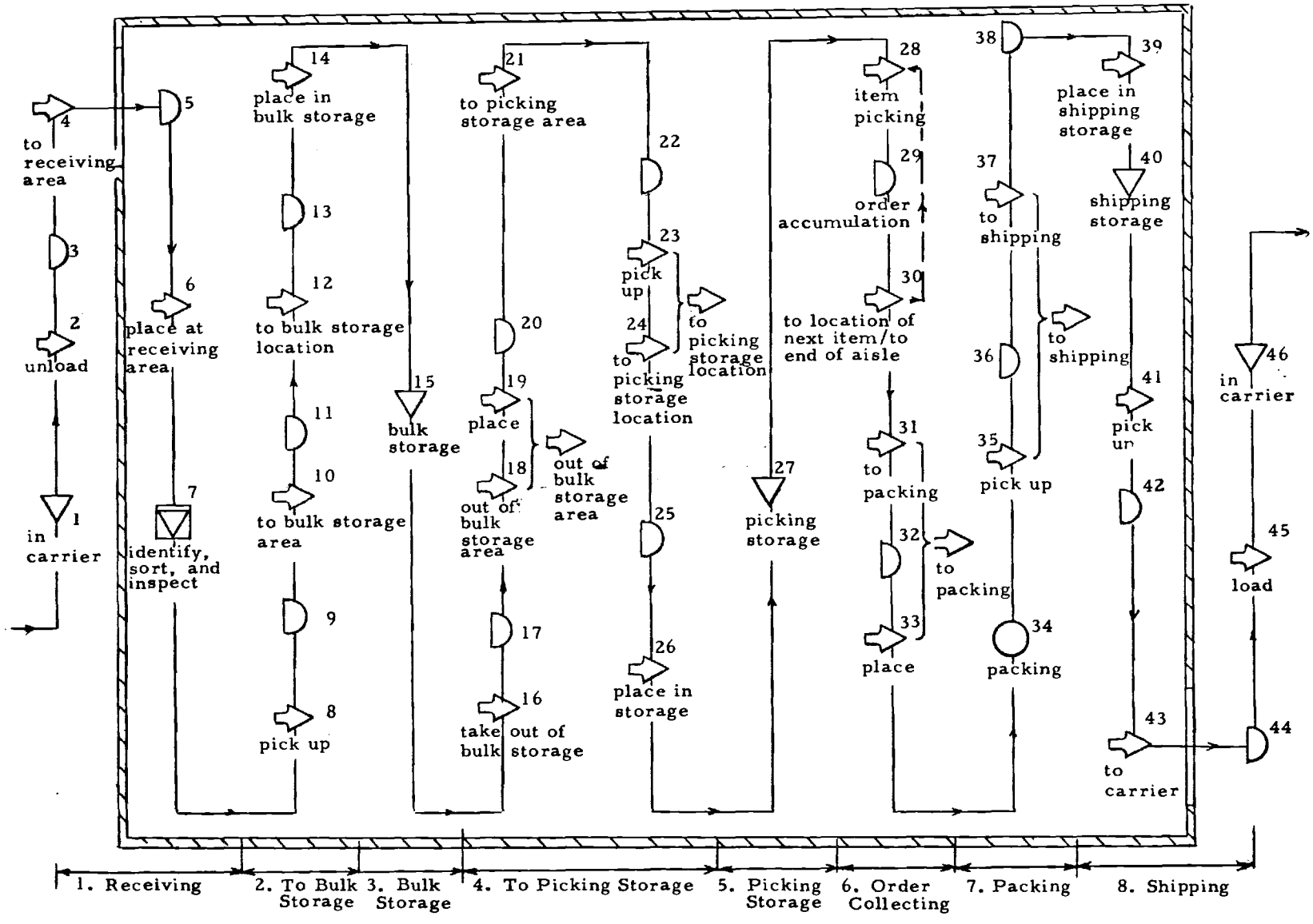
c. Packing can include making a unit load from one order (several line items).

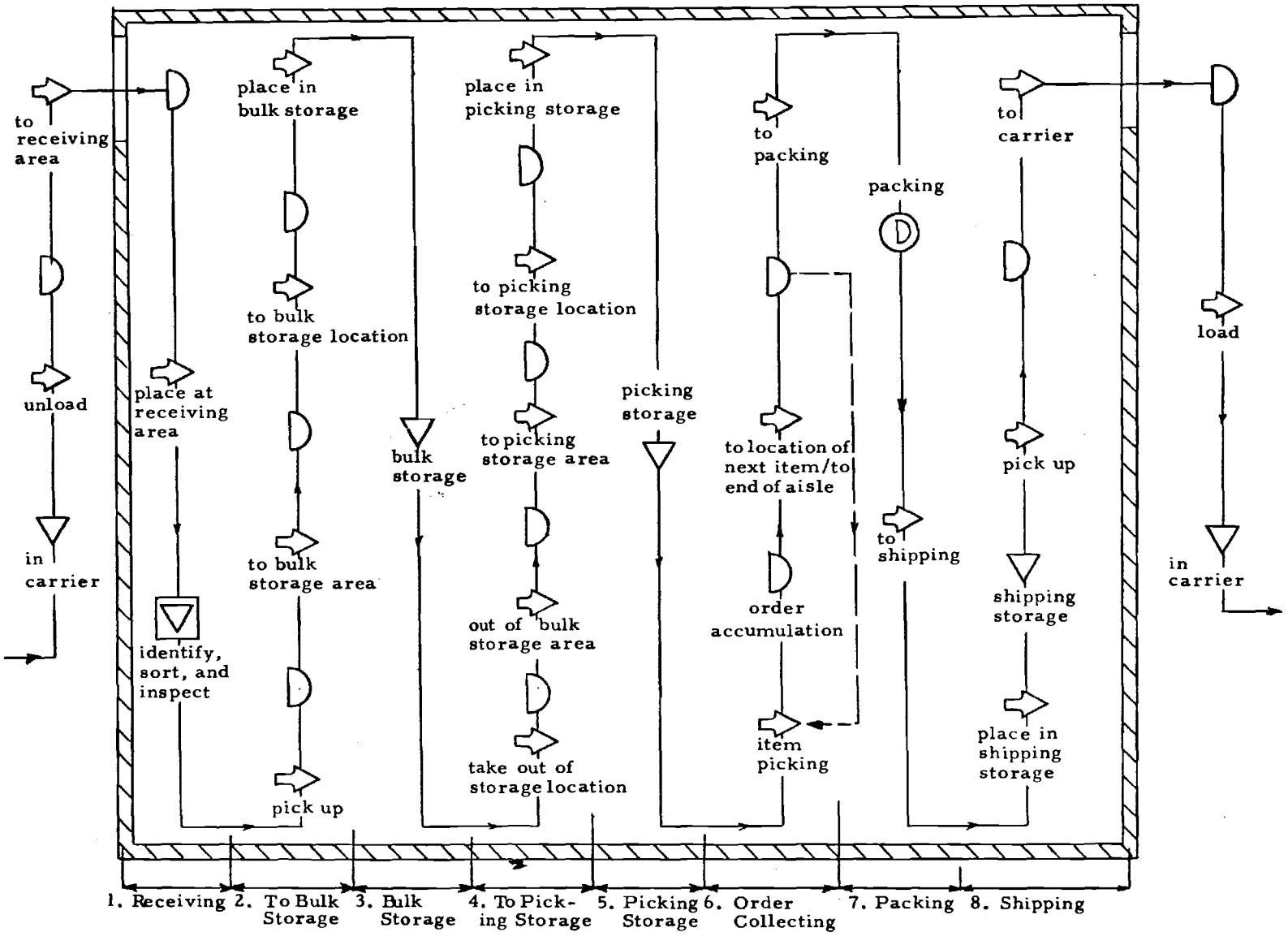
The process charts immediately following speak for themselves. The three process charts have been combined into one chart, as shown on page 168. With some slight modifications, page 168 can be transformed into a chart giving a fairly good picture of a general warehouse. This final result is shown on page 169.


Warehouse 1
Warehouse 2
Warehouse 3
Receiving
To Bulk Storage
To Picking Storage
1 In Carrier at Receiving
2 Unload
3 On Hand cart
4 To Receiving Area
5 On Hand cart
6 Place at Receiving Area
7 Identify, Sort, Inspect
8 Place on Hand Cart
9 On Hand Cart
10 To Bulk Storage
11 Wait for Stacker Crane
12 To Storage Location
13 On Hand Cart
14 Place in Storage
15 Bulk Storage
16 Take out of Storage
17 On Hand Cart
18 Out of Storage Area
Unload
To Receiving Area
Place at Receiving Area
Identify, Sort, Inspect
Place on Conveyor
To Bulk Storage Area
Wait for Stacker Crane
To Storage Location
Place in Storage
Bulk Storage
Take out of Storage
To End of Aisle


Warehouse 1
Warehouse 2
Warehouse 3
To Picking Storage
Order Collecting
Packing
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
Place on Conveyor
Place on Conveyor
On Hand Cart
To Picking Storage Area
To Picking Storage Area
Wait
Pick up from Conveyor
To Picking Storage Location
To Picking Storage Location
To Picking Storage Location
Place in Picking Storage
Let in Right Flow Rack
Place in Picking Storage
Picking Storage
Picking Storage
Picking Storage
Item Picking
Item Release
Item Picking
On Hand Cart - Accumulation
On Conveyor - Accumulation
On Track - Accumulation
To Location of Next Item/To End of Aisle
To Location of Next Item/To End of Aisle
To Packing
To Packing
To Packing
Wait
Wait
Unload Truck
Unload Cart
Wait
Pack
Pack/Strap
Pack/Strap
Place on Hand Cart
Pick up Order
Pick up Orders


Warehouse 1
Warehouse 2
Warehouse 3
Packing
Shipping
36
On Hand Cart
37
To Shipping
To Shipping
To Shipping
38
On Hand Cart
39
Place in Shipping Storage
Place in Shipping Storage
Place in Shipping Storage
40
Shipping Storage
Shipping Storage
Shipping Storage
41
Pick up
Pick up
Pick up
42
On Hand Cart
43
To Carrier
To Carrier
To Carrier
44
On Hand Cart
45
Load
Load
Load
46
In Carrier
In Carrier
In Carrier


1 in carrier
2 unload
3
4 to receiving area
5
6 place at receiving area
7 identify, sort, and inspect
8 pick up
9
10 to bulk storage area
11
12 to bulk storage location
13
14 place in bulk storage
15 bulk storage
16 take out of bulk storage
17
18 out of bulk storage area
19 place
20
21 to picking storage area
22
23 pick up
24 to picking storage location
25
26 place in storage
27 picking storage
28 item picking
29 order accumulation
30 to location of next item/to end of aisle
31 to packing
32
33 place
34 packing
35 pick up
36
37 to shipping
38
39 place in shipping storage
40 shipping storage
41 pick up
42
43 to carrier
44
45 load
46 in carrier
to picking storage location
to shipping
to packing
1. Receiving
2. To Bulk Storage
3. Bulk Storage
4. To Picking Storage
5. Picking Storage
6. Order Collecting
7. Packing
8. Shipping


to receiving area
unload
in carrier
place at receiving area
identify, sort, and inspect
place in bulk storage
to bulk storage location
to bulk storage area
pick up
bulk storage
place in picking storage
to picking storage location
to picking storage area
out of bulk storage area
take out of storage location
picking storage
to packing
to location of next item/to end of aisle
order accumulation
item picking
packing
to shipping
to carrier
pick up
shipping storage
place in shipping storage
load
in carrier
1. Receiving
2. To Bulk Storage
3. Bulk Storage
4. To Picking Storage
5. Picking Storage
6. Order Collecting
7. Packing
8. Shipping

APPENDIX B

OVERVIEWS OF EQUIPMENT ALTERNATIVES

Sub-function: 1. Receiving

Level of Mechanization	Unload	To Receiving Area	Place at Receiving Area
Hand 1	Hand	Hand (Carrying)	Hand
Hand Equipment 2	Hand Lift Truck	Platform Truck	
Mechanized Hand Equipment 3	Hoist Hand Lift Truck	Platform Truck	Hoist
Gravity Equipment 4		Gravity Conveyor Chute	
Power Equipment, Hand Control 5	Overhead Crane Fork Truck/Crane Truck/Reach Truck Hoist	Conveyors, Different Types Tractor	
Power Equipment, Remote Hand Control 6	Overhead Crane Hoist	Driverless Tractor Conveyors, Different Types	
Power Equipment, Program Control 7		Conveyors, Different Types Driverless Tractor	
Power Equipment, Feedback Control 8		Conveyors, Different Types Driverless Tractor	
Adaptive System Equipment 9		Conveyor: Some Types: Monorail, Trolley, Tow	
Fully Automated System Equipment 10		Conveyors: Monorail, Trolley, Tow	

Sub-function: 2. To Bulk Storage

Level of Mechanization	Pick up at Receiving Area	To Bulk Storage Area	To Bulk Storage Location	Place in Storage
Hand 1	Hand	Hand Carrying		Hand
Hand Equipment 2	Hand Lift Truck Platform Truck	Roller Conveyor		
Mechanized Hand Equipment 3	Hoist Hand Lift Truck Platform Truck	Conveyors: Monorail, Trolley, Roller, Tow		Hoist
Gravity Equipment 4		Gravity Conveyor Chute		
Power Equipment, Hand Control 5	Fork Truck Conveyor: Different Types Hoist	Tractor		
Power Equipment, Remote Hand Control 6	Overhead Crane Hoist	Driverless Tractor Conveyor: Different Types	Stacker Crane	
Power Equipment, Program Control 7		Conveyor: Different Types Driverless Tractor	Stacker Crane	
Power Equipment, Feedback Control 8		Conveyor: Different Types Driverless Tractor	Stacker Crane	
Adaptive System Equipment 9		Monorail, Trolley, Tow Conveyors	Stacker Crane	
Fully Automated System Equipment 10		Monorail, Trolley, Tow Conveyors	Stacker Crane	

Sub-function: 4. To Picking Storage

Level of Mechanization	Take out of Storage	To end of Aisle	To Picking Storage Area	To Picking Storage Location	Place in Picking Storage
Hand 1	Hand	Hand - Carrying			Hand
Hand Equipment 2		Platform Truck Hand Lift Truck Roller Conveyor			
Mechanized Hand Equipment 3	Hoist	Platform Truck Hand Lift Truck Conveyors: Monorail, Trolley, Tow			Hoist
Gravity Equipment 4		Gravity Conveyor Chute			
Power Equipment, Hand Control 5	Hoist	Overhead Crane Fork Truck Tractor Conveyor: Different Types Manned Stacker Crane			
Power Equipment, Remote Hand Control 6	Hoist	Overhead Crane Driverless Tractor Conveyor: Different Types Manned Stacker Crane			
Power Equipment, Program Control 7		Driverless Tractor Conveyor: Different Types Stacker Crane			
Power Equipment, Feedback Control 8		Driverless Tractor Conveyor: Different Types Stacker Crane			
Adaptive System Equipment 9		Monorail, Trolley, Tow Conveyors Stacker Crane			
Fully Automated System Equipment 10		Monorail, Trolley, Tow Conveyors Stacker Crane			

Sub-function: 6. Order Collecting

Level of Mechanization	Item Picking	To Location of Next Item/to End of Aisle	To Packing Area
Hand 1	Hand	Hand - Carrying/with Trough or Basket	
Hand Equipment 2		Platform Truck Handlift Truck Roller Conveyor	
Mechanized Hand Equipment 3	Hoist	Platform/Handlift Truck Conveyors: Monorail, Trolley, Tow	
Gravity Equipment 4		Gravity Conveyors	Chute
Power Equipment, Hand Control 5	Hoist	Overhead Crane Tractor Fork Truck Different Type Conveyors Order Picking Vehicle	
Power Equipment, Remote Hand Control 6	Hoist	Overhead Crane Conveyor: Different Types Driverless Tractor Order Picking Vehicle	
Power Equipment, Program Control 7		Conveyor: Different Types Driverless Tractor Order Picking Vehicle	
Power Equipment, Feedback Control 8		Conveyor: Different Types Driverless Tractor Order Picking Vehicle	
Adaptive System Equipment 9		Monorail, Trolley, Tow Conveyor Order Picking Vehicle	
Fully Automated System Equipment 10		Monorail, Trolley, Tow Conveyor Order Picking Vehicle	

Sub-function: 7. Packing

Level of Mechanization		To Shipping Area
Hand	1	Hand - Carrying
Hand Equipment	2	Industrial Trucks Roller Conveyor
Mechanized Hand Equipment	3	Industrial Trucks Monorail, Trolley, Tow Conveyors
Gravity Equipment	4	Gravity Conveyor Chute
Power Equipment, Hand Control	5	Conveyors: Different Types Overhead Crane Fork Truck Tractor
Power Equipment, Remote Hand Control	6	Conveyors: Different Types Overhead Crane Driverless Tractor
Power Equipment, Program Control	7	Conveyors: Different Types Driverless Tractor
Power Equipment, Feedback Control	8	Conveyors: Different Types Driverless Tractor
Adaptive System Equipment	9	Monorail, Trolley, Two Conveyors
Fully Automated System Equipment	10	Monorail, Trolley, Two Conveyors

Sub-function: 8. Shipping

Level of Mechanization	Place in Shipping Storage	Take out of Shipping Storage	To Truck	Load
Hand 1	Hand	Hand	Carry	Hand
Hand Equipment 2			Platform Truck	
	Hand Lift Truck			
	Hoist	Hoist	Roller Conveyor	Hoist
Mechanized Hand Equipment 3	Hoist	Hoist	Roller, Trolley, Tow, Monorail Conveyors; Platform Truck	Hoist
	Hand Lift Truck			
Gravity Equipment 4			Gravity Conveyor Chute	
Power Equipment, Hand Control 5	Hoist	Hoist	Conveyors: Different Types	Hoist
	Overhead Crane			
	Fork Truck			
			Tractor	
Power Equipment, Remote Hand Control 6	Hoist	Hoist	Conveyors: Different Types	Hoist
	Overhead Crane			
			Driverless Tractor	
Power Equipment, Remote Hand Control 7			Conveyors: Different Types Driverless Tractor	
Power Equipment, Feedback Control 8			Conveyors: Different Types Driverless Tractor	
Adaptive System Equipment 9			Monorail, Trolley, Tow Conveyors	
Fully Automated System Equipment 10			Monorail, Trolley, Tow Conveyors	

APPENDIX C

IDENTIFICATION OF FACTORS RELEVANT TO THE PROBLEM OF SELECTING WAREHOUSE EQUIPMENT

APPENDIX C

IDENTIFICATION OF FACTORS RELEVANT TO THE PROBLEM OF SELECTING WAREHOUSE EQUIPMENT

The method followed here is described in Reference (2).

a. "Selecting warehouse equipment" is classified as an activity of the group, "storage and warehousing." This activity has not been divided into sub-activities.

b. Factors relevant to this activity can be identified from a master list of over 500 factors. This can be done in three steps:

Step 1. Verify headings of the master list for applicability. Headings of groups of factors that might be relevant are summarized on page 179.

Step 2. Verify subheadings of the master list for applicability. Sub-headings of the groups of factors that were identified under Step 1 are checked for relevancy with respect to this particular problem. The result is shown on page 179.

Step 3. Verify factors. The factors of the groups that were selected by their sub-headings in Step 2 are now checked for relevancy. This is shown on pages 181-200. Two grading possibilities have been distinguished:

1. Of primary importance. This is indicated with two check marks (**).

2. Of secondary importance. This is indicated by one check mark (*).

The factors of primary importance have been summarized into a list that is presented in Chapter V.

Selected Headings of Groups of Factors

Heading	Relevant
1. Material	yes
2. Move	yes
3. Method	perhaps
4. Building	perhaps
5. Production Equipment	no
6. Product	yes
7. Production	perhaps
8. Storage and Warehousing	yes
9. Market	perhaps
10. Personnel	yes
11. Costs	yes
12. Intangibles	yes

Selected Sub-headings of Groups of Factors

Heading	Sub-heading	Relevant
1. Material	a. Type	yes
	b. Characteristics	yes
	c. Quantities	yes
2. Move	a. Source and Destination	yes
	b. Logistics	perhaps
	c. Characteristics	yes
	d. Type	no
4. Building	a. General	perhaps
	b. Internal	perhaps
	c. External	perhaps
	d. Aisles	yes
	e. Doors	yes
	f. Ceiling	yes
	g. Columns	yes
	h. Floor	yes
	i. Site	no
	j. Miscellaneous	perhaps

	Heading		Sub-heading	Relevant
6.	Product		Product	yes
7.	Production	a.	Production Characteristics	perhaps
		b.	Production Method	no
		c.	Production Control	perhaps
8.	Storage and Warehousing	a.	Materials, see 1	
		b.	Equipment	no
		c.	Facilities, see 4	
		d.	Shipping and Receiving	yes
		e.	Operations	perhaps
		f.	Order	yes
		g.	Storage Space	yes
9.	Market	a.	Market Characteristics	perhaps
		b.	Consumer Factors	no
		c.	Trends	perhaps
		d.	Distribution	no, see 8a
		e.	Miscellaneous	perhaps
10.	Personnel	a.	Personnel Characteristics	yes
		b.	Working Conditions	yes
11.	Costs		Not applicable for Pre-selection stage	
12.	Intangible Factors	a.	Equipment/Method	no
		b.	Management	yes
		c.	External Factors	perhaps
		d.	Miscellaneous	perhaps

Master List of Factors To Be Considered in Operations and Facilities Systems Design

	Relevant	Importance
1. MATERIAL FACTORS	yes	
1a. Type of Material	yes	**
Unit		
Bulk		
Liquid		
Gas		
1b. Material Characteristics	yes	
Shape (Form)		**
Dimension (Size)		**
Temperature		
Weight per Unit		**
Handleability		
Fragility		**
Machine Handleable		*
Palletizable		*
Stackability		*
Numbers per Unit Load		*
Density - Weight		*
Acidity/Alkalinity		
Flowability		
Friability		
Corrosiveness		
Light Sensivity		
Evaporation		
Toxicity		
Flammability		
Shrinkage		
Deteriorates		
Uniformity of Units		**
Decomposes		
Harmful		
Interlocks		
Oily		

	Relevant	Importance
Unusual Characteristics		
Builds Up		
Static Electricity		
Dusty		
Aerates		
Degradable		
Hygroscopic		
Packs		
Fluffy		
1c. Quantities	yes	
Total, Maximum and Minimum Quantity		**
Average Quantity[1]		**
Fluctuation		
Seasonality		**
Trends		**
Number of Units[1]		
Annual Quantities[1]		**
Maximum Inventory		See 8g
Quantity per Delivery		**
Quantity per Move		
Quantity per Handling Unit		**
Frequency Distribution		**
2. MOVE FACTORS	yes	
2a. Source and Destination	yes	
Scope: Area Involved		**
Point to Point		
Activities Involved		
Route: Plane		
Profile		
Path		**
Level		**
Origin		**
Destination		

[1] Combined into one factor, "Average Quantity."

	Relevant	Importance
Running Surface		See 4h
Storage Requirements En Route		
Handling Requirements En Route		
2b. Logistics		
External[1]		**
Internal		*
Load/Unload Level[1]		
Load/Unload Method[1]		
2c. Characteristics		
Distance		**
Frequency		See 1c
Rate		
Speed		
Motion		
Traffic		**
Environment		*
Per Cent Transportation		
Per Cent Handling		
Sequence		**
2d. Type of Move	no	
Transporting		
Conveying		
Maneuvering		
Positioning		
Transferring		
3. METHOD (HANDLING) FACTORS	perhaps	
3a. Factors in Handling Unit		
Items per Handling Unit		
Load Support Method		
Container		

[1] Combined into one factor, "External Factors."

	Relevant	Importance
Handling Units per Total Quantity		
Weight		
Number		
3b. Materials Handling Equipment Factors		
Function		
Type Indicated		
Desired Characteristics		
Amount		
Cost		
3c. Manpower Factors		
Time per Move		
Hours per Year		
Hourly Cost		
Annual Cost		
4. BUILDING FACTORS	perhaps	
4a. General	perhaps	
Dimensions (Size)		**
Shape		**
Type		*
Construction		**
Construction Materials		
Structural Design		*
Number of Floors		**
Orientation on Site		
Space Available		See 8
Flexibility		*
4b. Internal Factors	perhaps	
Personnel		See 10
Legal Requirements		**
Office Factors		
Production Factors } Space		
Storage Factors } Requirements		
Warehouse Factors		See 8

	Relevant	Importance
4c. External Factors	perhaps	
Service		
Auxiliary		
Utilities		
Yards		
Grounds		
Site		
4d. Aisles	yes	
Width		**
Number		**
Location		**
Type		*
4e. Doors	yes	
Number		*
Size		*
Height		*
Type		*
Location		*
4f. Ceiling	yes	
Ceiling Spacing		*
Ceiling Height		**
Clear Height		**
Stacking Height		**
Load on Roof		
Load on Trusses, Joists		*
4g. Columns	yes	
Column Spacing		**
Column Loading		**
Column Type		*
Overhead Load Capacity		*
4h. Floor	yes	
Floor condition		*

	Relevant	Importance
Running Surface		**
Weight Limits, Carriers of Floor		**
Weight Limit, Floor Load		**
Area Required/Available		*
Physical Characteristics		*
4i. Site	no	
Size		
Roads and Highways		
Adequacy and Type of Land Transportation		
Community Acceptance		
Water Supply		
Expansion Possibilities		
Cost of Site		
Electrical Power		
Rail		
Natural Gas		
Water Transportation		
Facilities for Employee Transportation		
4j. Miscellaneous	perhaps	
Elevators		*
Ramps		*
Handling Methods		
Environment		*
Lighting		
5. PRODUCTION EQUIPMENT FACTORS	no	
5a. Mechanical Factors		
Capability of Performing Work		
Accuracy Attainable		
Dimensional Stability		
General/Special Purpose		
Flexibility		
Adaptability		
Life Expectancy		
Potential Obsolescence		

	Relevant	Importance
Compatibility with Other Equipment		
Feeding Method		
Materials of Construction		
Durability		
Reliability		
Physical Characteristics		
Foreseeable Technological Improvements		
Degree of Mechanization: Present Potential		
Relative Complexity		
Capacity		
Reserve Capacity		
Need for Subsequent Operations		
Safety		
Manpower		
Auxiliary Equipment Required		
Service Requirements		
Overtravel		
Number of Machines		
Height of Work Surface		
Height of Controls		
Noise Level		
Nature of Process		
Quality: Rejects		
Rework		
Returns		
Cost of Attaining		
Inspection Accuracy		
Space Required		
Scrap		
5b. Operating Factors		
Interruptibility of Process		
Efficiency		
Set-up Time		
Debugging Time		
Frequency of Use		
Per Cent of Time Used		
Safety		
Installation Time		

	Relevant	Importance
Manpower Requirements:		
Skill		
Amount		
Training		
Cost		
Supervision		
Inspection		
Handling		
Human Factors		
Physical Effort Required		
Manpower Utilization		
6. PRODUCT FACTORS	yes	
Price-Volume Relationship		
Life Cycle[1]		**
Durability		*
Complementary Products		
Substitute Products		
Product Quality		
Service and Repair Requirements		
Acceptability		
Selling Price		
Stability		*
Technological Advantages		
Package Characteristics (Type, Function)		**
Sales Unit		**
Customer Desires		
Desired Features		
Likelihood of Change[1]		**
Product Standardization		*
Complexity of Product		*
Potential Obsolescence		*
Uses		
Design		*
History		
Produceability		*
Palletizable-Arrangeable in Unit Load		

[1]Combined into one factor, "Likelihood of Change of Product Mix."

	Relevant	Importance
7. PRODUCTION FACTORS	perhaps	
7a. Production Characteristics	perhaps	
Production Rate, per hour		
Lot Size		
Production Method: Continuous		*
Intermittent		
Job Lot		
Time to Get into Production		
Process Requirements:		
Quality		
Appearance		
Accuracy		
Finish		
Tolerance		
Special		
Process Specifications		
7b. Factors in the Production Method	no	
Direction of Flow		
Location of Items		
Related Work Places		
Delivery of Materials to . . .		
Removal of Materials from . . .		
Movement of Materials in . . .		
Principles of Motion Economy		
Hazards, Safety Requirements		
Overall Flow		
Mechanization Possibilities		
"Line" Possibilities		
Process or Product Layout		
Overall Materials Handling System		
Relative Distances in Work Place		
Operation Sequence		
Standard Time		
Expansion Possibilities		
Paperwork Involved		
Tool Location		
Material Location		
Location of Work Place in Material Flow		

	Relevant	Importance
Height of Work Place		
Relationships to Preceding and Following Operations		
Production Rate		
Batch or Continuous Production		
Economic Lot Size		
Flexibility		
Cycle Time		
Number of Duplicate Work Places		
Auxiliary Services Required		
Column Locations		
Items Required in Work Area		
Effect of Breakdown		
Monotony of Work		
Unavoidable Idle (Available Time)		
Supervision		
Area Requirements per Activity		
Line Balancing		
Average "in Process" Storage Time		
7c. Production Control	perhaps	
Paperwork		
Communications		*
8. STORAGE AND WAREHOUSING FACTORS	yes	
8a. Product/Material	See 1. Material	
8b. Warehouse Equipment	See 2. Move, and 3. Method	
8c. Facilities	See 4. Building	
8d. Shipping and Receiving		
Receipts and Shipments per Day		*
Frequency Distribution		See 1c

	Relevant	Importance
Sizes of Receipts and Shipments		*
Schedules		**
Shipping and Receiving Methods		*
Carrier Characteristics		**
Vendor/Customer Restrictions		*
Location		*
Relationship to Other Activities		*
Size of Receiving and Shipping Areas		*
8e. Operations		
Stock Location System		*
Order Picking Method		*
Communication System		*
Record-Keeping System		**
Information System		**
Inventory Policy		**
Replenishment Practices		*
Experience with Mechanization/ Automation		*
8f. Orders	yes	
Number of Customers		*
Orders per Day		**
Quantity per SKU		
Popularity Distribution		*
Order Mix		*
Issue Units		
Issue Volumes		
Need for Repacking		
Order Reading Time[1]		**
Order Filling Time[1]		
Order Lines per Day[1]		*
Order Documentation		See 8e
Service Requirements		
Total Order Delivery Time[1]		

[1]Combined into one factor, "Order Delivery Time."

	Relevant	Importance
8g. Storage Space	yes	
Stock Quantities		**
Space Type		*
Space Requirements		*
Rack Size and Spacing:		*
Pallet Spacing on Racks		
Pallet Rack Spacing		
Storage Time		
Total Volume		
Number of Items		**
Volume per Item		*
Pallet Size		See 1b
Pallet Arrangements (Layout)		**
Future Expansions		
9. MARKET FACTORS	perhaps	
9a. Market Characteristics	perhaps	
General Economic Conditions		**
Scope of Market		
Geographical Distribution		
Long-range Potential		
Growth Potential		*
Number of Customers		
Population Characteristics (Customers)		
9b. Consumer Factors	no	
Function of Product		
Performance		
Appearance		
Guarantee		
East of Operation		
Ease of Installation		
Life of Product		
Durability		
Service Requirements		
Service Availability		
Safety		

	Relevant	Importance
Capacity		
Quality		
Value Received		
Complexity		
Packaging		
Style		
Range of Sizes		
Colors		
Desires, Needs, Wants		
Motives, Habits		
Income		
Occupation		
Age		
Sex		
Brand Preference		
Product and Company Loyalty		
Demands		
9c. Trends	perhaps	
Past Sales		
Estimated Volume		
Trends in Industry		*
Degree of Competition		
Competitors' Activities		**
Economic Trends		*
Seasonality of Product		See 1b
Expected Market Share		
Competition Characteristics:		
Type		
Number		
Locations		
Future Developments		
Quality		
Price		
Sales Policies		
Activities		
Aggressiveness		
Supply		
Trends in Customer Characteristics		
Trends in Population Characteristics		

	Relevant	Importance
9d. Distribution	no See 8a	
Channels		
Methods		
Dealers' Attitude		
9e. Miscellaneous Factors	perhaps	
Sales Promotion Plans		
Sales Methods		
Governmental Regulations		*
Company Image		
Legal Restrictions		*
Company Reputation		
Management Ability		
Sales Force		
Public Relations		
Profit Potential		
Pricing Policies		
Advertising		
10. PERSONNEL FACTORS	yes	
10a. Personnel Characteristics	yes	
Age		
Sex		
Size		
Physical Capability		*
Intelligence		*
Education		*
Skill		**
Experience		*
Training		*
Effort Required		
Fatigue, Mental/Physical		**
Job Evaluation		
Group Interaction		
Compatibility of Operator with Equipment		*
Wage		**
Supervision		

	Relevant	Importance
Employees' Attitude		**
Management Attitude		**
Work Standards		*
Monotony		**
Satisfaction		**
Incentives		
Overall Morale		
Repetitiveness		
Employee Facilities and Services		
Motivation		**
Employee Satisfaction		**
Preferences of People Involved		*
10b. Working Conditions	yes	
Noise Level		**
Light Requirements		
Heating and Ventilation		**
Dust, etc.		
Building Characteristics		See 4
Vibration		
Window Location		
Operator Efficiency		*
Safety Hazards		*
Space Requirements		*
Sit or Stand		*
Comfort		**
Number of Operators		*
Movement during Cycle		*
Injuries		**
Fatigue		**
11. COST FACTORS	no[1]	
11a. Material Costs		
Cost of Raw Materials		
Cost of Incoming Parts		
Cost of Unitizing Materials (Unit Loads)		

[1]Cost factors are considered in the final selection stage of the selection procedure. See Chapter V.

	Relevant	Importance
Fuel, Power		
Lubrication		
Maintenance Parts and Supplies		
Scrap Prices		
Cost of Packaging Materials		
11b. Labor Costs		
Labor in Storage Departments		
Labor in Handling		
Direct Labor: Operating Personnel		
Supervisory Personnel		
Clerical Help		
Maintenance Personnel		
Others		
11c. Equipment Costs		
(1) Investments		
Costs of Storage Equipment		
Costs of Handling Equipment		
Costs of Handling Aids		
Costs of Machines		
(2) Operating Costs		
Finishing Costs		
Start-up Costs		
Operating (Running) Costs		
Handling Costs		
Inventory Control Costs		
Production Control Costs		
Maintenance Costs		
11d. Building and Site Costs		
Costs of Space		
Construction Costs		
Cost of Addition vs. New Building		
Costs of Plant Site		
11e. Miscellaneous Costs		
Costs of Handling System		

	Relevant	Importance
Costs of Owning vs. Leasing		
Costs of Space Occupied		
Cost of Capital (Interest Rate)		
Depreciation		
Taxes		
Insurance		
Demurrage Costs		
Downtime Charges		
Existing Wage Rates		
Return on Investment		
Investment Required		
Funds Available		
Relative Payoff		
Inventory Value		
Legal Restrictions		
State and Local Tax Regulations		
Inventory Costs		
Travel Expenses		
Costs of Follow-up		
Costs of Inventory Control		
Costs of Production Control		
Storage Costs		
Construction Costs		
Warehousing Costs		
Transportation Costs		
Damage Costs		
Pilferage Costs		
Unit Costs		
Manufacturing Costs		
Costs of Production		
Discounts		
Costs of Receiving/Inspection		
Paperwork Costs		
Costs of Waste		
Subsidies		
Investment Needed		
Costs of Rejects		
Overhead		
Administration Costs		
Selling Costs		

	Relevant	Importance
11f. Indeterminate Costs		
Changes in Overhead		
Changes in Quality		
Reduction in Physical Effort		
Percentage of Time Equipment is Utilized		
Turnover of Work in Process		
Changes in Line Balance		
Economic Trends		
Financial Arrangements		
Depreciation Policy		
Trends in Equipment Costs		
Reduction in Paperwork		
Supervision Required		
Volume of In-Process Work		
Changes in Material Flow (Work Flow)		
Costs, Present vs. Future		
Space Occupied		
Effect on Inventory Value		
Changes in Production Rate		
Payment Terms		
Inflation		
Cash Flow		
Source of Funds		
12. INTANGIBLE FACTORS	yes	
12a. Equipment/Method Factors	perhaps	
Quality of Equipment		*
Durability of Equipment		*
Compatibility of Equipment		*
Standardization of Equipment and Components		*
Flexibility		*
Adaptability		*
Complexity		*
Safety		*
Rate of Obsolescence		*
Manufacturing Reputation		*

	Relevant	Importance
Availability of Equipment		*
Post-Sale Advice and Service		*
Availability of Service		*
Availability of Parts		*
Quality of Service		*
12b. Management	yes	
Financial Policy		**
Economic Survival Goals		*
Effect of Future Changes		*
Plans for Expansion		**
Labor Relations		
Effect on Morale		**
Increased Salability of Product		
Improved Customer Service		*
Pride in Installation		*
Complaints		
Degree of Accomplishments of Objectives		
Public Relations Value		*
Union's Attitude		**
Funds Available		*
Inventory Policy		
History of Company		
Profit Desired		*
12c. External Factors	perhaps	
Labor Legislation		**
Safety Laws		**
Union Influences		**
Job Market/Labor Availability		**
Work Schedule (Hours/Week; Hours/Day)		*
Geographical Area		
Climate (Weather)		
Economic Climate		
External Facilities, and Their Relationships to Internal Facilities		
Volume of Traffic		
Proximity of Air Transportation		
Labor Potential (Quality)		*

	Relevant	Importance
Community Acceptance		
Existing Wage Rates		*
State and Local Taxes		*
Type of Local Industry		
Commercial Services		
Existing Working Conditions		*
Water/Air Pollution Regulations		
Governmental Regulations		*
Suppliers of Incoming Parts and Raw Materials:		
Availability		
Reliability		
Ability to Provide Service		
Reputation		
Management Ability		
Availability of Building		
12d. Miscellaneous	perhaps	
Efficiency of Plant Layout		*
Space Requirements per Department		
Relative Importance of Different Activity Areas		
Activity Relationships		*
Separate Areas for Separate Activities		
Plans: Quality of Data		
Accuracy of Estimates		
Quality of Plans		
Validity of Decisions		
Allowance for Errors		

APPENDIX D

IDENTIFICATION OF THE FACTORS RELEVANT TO THE SELECTION OF THE APPROPRIATE WAREHOUSE TYPE

	Relevancy to Selection of Warehouse Type
1. MATERIAL FACTORS	
1a. Type of Material (Unit, Bulk, Liquid, Gas)	**
1b. Material Characteristics	
Shape/Form of Handling Units	**
Dimensions of Handling Units	**
Uniformity of Handling Units	**
Weight of Handling Units	*
Fragility of Material	*
1c. Quantities	
Total Quantity, Average	**
Total Quantity, Maximum/Peak Quantities	**
Seasonality	*
Frequency Distribution	
Quantity per Delivery (from Supplier) per Item	**
Quantity per Order per Item	**
2. MOVE FACTORS	
2a. Source and Destination	
Area Involved	*
Complexity of Activity (Activities)	
Path	
Level(s) of Route	
Number of Origins	
Number of Destinations	
2b. Logistics	
External Factors	*

**Factor of primary importance.

*Factor of secondary importance.

	Relevancy to Selection of Warehouse Type
2c. Characteristics	
Distance	*
Sequence	
(Cross) Traffic	
3. BUILDING FACTORS	
3a. General	
Dimensions of Building	*
Shape of Building	
Number of Floors	
Space Available	*
Construction	
3b. Internal Factors	
Legal Requirements	
Space Requirements for Storage	*
3c. Aisles	
Width	
Number	
Location	
3d. Ceiling	
Ceiling Height	
Clear Height	
Stacking Height	
3e. Columns	
Column Spacing	
Column Load Capacity	

	Relevancy to Selection of Warehouse Type
3f. Floor	
Weight Limits	
Running Surface	
3g. Miscellaneous	
Ramps	
4. PRODUCT FACTORS	
Sales Unit	
Likelihood of Change	
Package Characteristics	*
5. STORAGE AND WAREHOUSING	
5a. Shipping and Receiving	
Schedules	
Carrier Characteristics	
5b. Operations	
Record-keeping System	*
Information System	
Inventory Policy	*
Experience with Mechanization/Automation	
5c. Storage Space	
Stock Quantities	**
Number of Items Stored	*
Future Expansions	*
5d. Orders	
Number of Orders/Day	**
Order Delivery Time	**

	Relevancy to Selection of Warehouse Type
6. MARKET FACTORS	
General Economic Conditions	
Growth Potential and Trends	*
Activities of Competitive Firms	**
7. PERSONNEL	
7a. Personnel Requirements	
Physical Requirements	
Skill Required	
Wages	
Employees' Attitude	*
Managers' Attitude	*
Motivation/Satisfaction	
7b. Working Conditions	
Noise	
Heat	
Comfort	
Injuries	
Fatigue	
Monotony of Job	
8. INTANGIBLES	
Financial Policy	
Effect on Morale	
Union Attitude	
Labor Legislation	
Safety Laws	
Labor Market	

APPENDIX E

IDENTIFICATION OF THE FACTORS RELEVANT TO THE SELECTION OF THE APPROPRIATE CLASS OF MECHANIZATION/AUTOMATION

1. MATERIAL FACTORS

1a. Type of Material (Unit, Bulk, Liquid, Gas)	**
1b. Material Characteristics	
Shape/Form of Handling Units	**
Dimensions of Handling Units	**
Uniformity of Handling Units	**
Weight of Handling Units	**
Fragility of Material	*
1c. Quantities	
Total Quantity, Average	**
Total Quantity, Maximum	*
Seasonality	*
Frequency Distribution	**
Quantity per Delivery (from Supplier) per Item	*
Quantity per Order per Item	*

2. MOVE FACTORS

2a. Source and Destination	
Area Involved	**
Complexity of Activity (Activities)	*
Path	*
Level(s) of Route	*
Number of Origins	*
Number of Destinations	*
2b. Logistics	
External Factors	*
2c. Characteristics	
Distance	**
Sequence	
(Cross) Traffic	*

**Factor of primary importance.

*Factor of secondary importance.

3. BUILDING FACTORS

3a. General

Dimensions of Building	*
Shape of Building	*
Number of Floors	
Space Available	*
Construction	

3b. Internal Factors

Legal Requirements	
Space Requirements for Storage	*

3c. Aisles

Width	*
Number	
Location	

3d. Ceiling

Ceiling Height	*
Clear Height	*
Stacking Height	*

3e. Columns

Column Spacing	*
Column Load Capacity	*

3f. Floor

Weight Limits	
Running Surface	

3g. Miscellaneous

Ramps	

4. PRODUCT FACTORS

Sales Unit	
Likelihood of Change	**
Package Characteristics	*

5. STORAGE AND WAREHOUSING

5a. Shipping and Receiving

Schedules	
Carrier Characteristics	*

5b. Operations

Record-keeping System	**
Information System	**
Inventory Policy	
Experience with Mechanization/Automation	**

5c. Storage Space

Stock Quantities	**
Number of Items Stored	**
Future Expansions	**

5d. Orders

Number of Orders/Day	**
Order Delivery Time	**

6. MARKET FACTORS

General Economic Conditions	**
Growth Potential and Trends	**
Activities of Competitive Firms	**

7. PERSONNEL

7a. Personnel Requirements

Physical Requirements	*

Skill Required	*
Wages	**
Employees' Attitude	**
Managers' Attitude	**
Motivation/Satisfaction	*

7b. Working Conditions

Noise	*
Heat	*
Comfort	**
Injuries	*
Fatigue	**
Monotony of Job	**

8. INTANGIBLES

Financial Policy	**
Effect on Morale	*
Union Attitude	*
Labor Legislation	
Safety Laws	
Labor Market	**

APPENDIX F

IDENTIFICATION OF THE FACTORS RELEVANT TO THE SELECTION OF THE APPROPRIATE LEVEL OF MECHANIZATION/AUTOMATION

1. MATERIAL FACTORS

1a. Type of Material (Unit, Bulk, Liquid, Gas)	*
1b. Material Characteristics	
Shape/Form of Handling Units	**
Dimensions of Handling Units	**
Uniformity of Handling Units	**
Weight of Handling Units	**
Fragility of Material	**
1c. Quantities	
Total Quantity, Average	**
Total Quantity, Maximum/Peak Quantities	**
Seasonality	**
Frequency Distribution	**
Quantity per Delivery (from Supplier) per Item	
Quantity per Order per Item	

2. MOVE FACTORS

2a. Source and Destination	
Area Involved	**
Complexity of Activity (Activities)	**
Path	**
Level(s) of Route	*
Number of Origins	**
Number of Destinations	**
2b. Logistics	
External Factors	*
2c. Characteristics	
Distance	**
Sequence	*

** Factor of primary importance.

* Factor of secondary importance.

(Cross) Traffic	**

3. BUILDING FACTORS

3a. General

Dimensions of Building	*
Shape of Building	*
Number of Floors	
Space Available	*
Construction	

3b. Internal Factors

Legal Requirements	
Space Requirements for Storage--Total Storage Space	**

3c. Aisles

Width	**
Number	*
Location	*

3d. Ceiling

Ceiling Height	**
Clear Height	**
Stacking Height	*

3e. Columns

Column Spacing	**
Column Load Capacity	**

3f. Floor

Weight Limits	*
Running Surface	**

3g. Miscellaneous

Ramps	

4. PRODUCT FACTORS

Sales Unit	*
Likelihood of Change	**
Package Characteristics	*

5. STORAGE AND WAREHOUSING

5a. Shipping and Receiving

Schedules	*
Carrier Characteristics	*

5b. Operations

Record-keeping System	**
Information System	**
Inventory Policy	*
Experience with Mechanization/Automation	*

5c. Storage Space

Stock Quantities	**
Number of Items Stored	**
Future Expansions	**

5d. Orders

Number of Orders/Day	*
Order Delivery Time	*

6. MARKET FACTORS

General Economic Conditions	**
Growth Potential and Trends	**
Activities of Competitive Firms	**

7. PERSONNEL

7a. Personnel Requirements

Physical Requirements	**
Skill Required	**
Wages	**
Employees' Attitude	**
Managers' Attitude	**
Motivation/Satisfaction	*

7b. Working Conditions

Noise	**
Heat	
Comfort	*
Injuries	*
Fatigue	**
Monotony of Job	**

8. INTANGIBLES

Financial Policy	**
Effect on Morale	*
Union Attitude	
Labor Legislation	*
Safety Laws	*
Labor Market	**

			Step 2							Step 3			Step 4										Step 5	
			Warehouse Type							Class of Mechanization			Level of Mechanization										Equipment Alternatives	
			1	2	3	4	5	6	7	Manual	Mechanized	Automated	1	2	3	4	5	6	7	8	9	10	1	2
1. Type of material	unit		x	x	x	x	x	x	x	x	x	x												
	bulk		-	-	-	-	-	-	-	-	-	-												
	gas		-	-	-	-	-	-	-	-	-	-												
	liquid		-	-	-	-	-	-	-	-	-	-												
2. Shape and/or form of handling units	Flow 1	regular	x	x	x	x	x	x	x															
		irregular	x			x																		
	Flow 2	regular	x	x	x	x	x	x	x															
		irregular	x	x		x	x	x																
	Flow 3	regular	-	-	-	x	x	x	x															
		irregular	-	-	-	x	x																	
Flow(s) under investigation		regular								x	x	x	x	x	x	x	x	x	x	x	x	x		
		irregular								x	x		x	x	x	x	x	x	x					
3. Dimensions of handling units	Flow 1	small	x			x																		
		medium	x	x	x	x	x	x	x															
		large		x	x		x	x	x															
	Flow 2	small	x	x		x	x	x																
		medium	x	x	x	x	x	x	x															
		large			x				x															
	Flow 3	small	-	-	-	x	x	x																
		medium	-	-	-	x	x	x	x															
		large	-	-	-			x	x															
Flow(s) under investigation		small								x	x	x	x	x	x	x	x	x	x	x	x	x		
		medium									x	x		x	x	x	x	x	x	x	x	x		
		large									x	x			x		x	x	x	x	x	x		
4. Uniformity of handling units	Flow 1	1 fixed size	x	x	x	x	x	x	x															
		various sizes	x			x																		
	Flow 2	1 fixed size	x	x	x	x	x	x	x															
		various sizes	x	x		x	x	x																
	Flow 3	1 fixed size	-	-	-	x	x	x	x															
		various sizes	-	-	-	x	x																	
Flow(s) under investigation		1 fixed size								x	x	x	x	x	x	x	x	x	x	x	x	x		
		various sizes								x			x	x	x	x	x	x						
5. Total average quantity		low	x	x		x	x			x	x		x	x	x	x								
		medium	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x					
		high			x		x	x			x	x				x	x	x	x	x	x	x		
6. Number of orders per day		low: 0-100	x	x	x					x	x													
		medium: 100-300				x	x	x	x	x	x	x												
		high: over 300				x	x	x	x		x	x												
7. Quantity per delivery (from supplier) per item		less than 1 unit load	x			x																		
		more than 1 unit load		x	x		x	x	x															
8. Quantity per order per item		less than 1 unit load	x	x		x	x	x																
		more than 1 unit load			x				x															
9. Peak quantities		low: less than 2 x average quantity	x	x	x								x	x	x	x	x	x	x	x	x	x		
		high: more than 2 x average quantity				x	x	x	x				x	x	x	x	x	x	x					
10. External factors		10a																						
		10b																						
11. Stock quantities per item (average)		low	x	x	x																			
		medium	x	x	x	x	x	x	x															
		high			x	x	x	x	x															
12. Required order delivery time		short: less than 1 day			x	x	x	x	x		x	x												
		long: more than 1 day	x	x						x	x													
13. Competitor's warehouse		(a) Type 1	x																					
		Type 2		x																				
		Type 3			x																			
		Type 4				x																		
		Type 5					x																	
		Type 6						x																
		Type 7							x															
TOTAL STEP 2																								
		(b) manual								x	x													
		mechanized								x	x	x												
		automated									x	x												
		(c) Level 1											x	x										
		Level 2											x	x	x									
		Level 3												x	x	x								
		Level 4													x	x	x							
		Level 5														x	x	x						
		Level 6															x	x	x					
		Level 7																x	x	x				
		Level 8																	x	x	x			
		Level 9																		x	x	x		
		Level 10																			x	x		
14. Weight of handling unit		0-50 pounds								x	x	x	x	x	x	x		x	x	x	x	x		
		50-1000 pounds									x	x		x	x	x	x	x	x	x	x	x		
		1000-10,000 pounds									x	x					x	x	x	x	x	x		
		over 10,000 pounds									x	x					x	x						
15. Area involved		small								x	x	x	x	x	x	x	x		x	x	x	x		
		medium									x	x		x	x	x	x	x	x	x	x	x		
		large									x	x					x	x	x	x	x	x		
16. Frequency distribution		no variability									x	x	x	x	x	x	x	x	x	x	x	x		
		low variability								x	x	x	x	x	x	x	x	x	x	x				
		high variability								x	x		x	x	x	x	x	x						
17. Likelihood of change of product		stable								x	x	x	x	x	x	x	x	x	x	x	x	x		
		change within 5 years								x	x		x	x	x	x	x							
		change within 1 year								x			x	x	x	x								
18. Present information system/ record keeping system		computerized										x								x	x	x	x	
		not computerized								x	x		x	x	x	x	x	x	x					
19. Total storage space		small								x	x		x	x	x	x	x	x						
		medium								x	x	x	x	x	x	x	x	x	x					
		large									x	x					x	x	x	x	x	x		
20. Number of line items stored		1-200								x	x		x	x	x	x	x	x						
		200-3000								x	x		x	x	x	x	x	x						
		3000-10,000									x	x					x	x	x	x				
		over 10,000									x	x					x	x	x	x	x	x		
21. Future expansions		yes									x	x					x	x	x	x	x	x		
		no								x	x	x	x	x	x	x	x	x	x					
22. General economic conditions		favorable									x	x					x	x	x	x	x	x		
		unfavorable								x	x		x	x	x	x	x							
23. Growth potential and trends		favorable									x	x					x	x	x	x	x	x		
		constant								x	x	x	x	x	x	x	x	x	x					
		unfavorable								x	x		x	x	x	x	x							
24. Wages		low								x	x		x	x	x	x	x	x						
		medium								x	x	x			x	x	x	x	x	x				
		high									x	x				x	x	x	x	x	x	x		
25. Employees' attitude towards mechanization and automation		positive									x	x		x	x	x	x	x	x	x	x	x		
		indifferent								x	x	x		x	x	x	x	x						
		negative								x			x	x										
26. Management attitude towards mechanization and automation		positive									x	x		x	x	x	x	x	x	x	x	x		
		indifferent								x	x	x		x	x	x	x	x	x					
		negative								x			x											
27. Comfort, physical requirements, fatigue		good situation														x	x	x	x	x	x	x		
		bad situation									x	x	x	x	x	x	x							
28. Monotony of job		monotonous									x	x	x	x	x				x	x	x	x		
		not monotonous								x	x		x	x	x	x	x	x	x	x	x	x		
29. Financial policy		invest/spend									x	x					x	x	x	x	x	x		
		save								x	x		x	x	x	x								
30. Labor market		favorable								x	x		x	x	x	x	x	x						
		unfavorable									x	x				x	x	x	x	x	x	x		
TOTAL STEP 3																								
31. Fragility of material		fragile											x	x	x		x		x	x	x	x		
32. Seasonality		constant											x	x	x	x	x	x	x	x	x	x		
		season variations											x	x	x	x	x	x	x	x	x	x		
		high season variations											x	x	x	x	x							
33. Complexity of activity(activities)		simple											x	x	x	x	x	x	x	x	x	x		
		complex											x	x	x		x	x	x	x	x	x		
		very complex											x	x			x							
34. Path		simple											x	x	x	x	x	x	x	x	x	x		
		compound											x	x	x	x	x	x	x	x	x	x		
		complex											x	x	x									

BIBLIOGRAPHY

1. De Greene, Kenyon B., Systems Psychology, McGraw-Hill.

2. van der Meer, Anne F., "The Identification of the Relevant Factors in Operations and Facilities Systems Design Activities," unpublished paper for Professor James M. Apple, Georgia Institute of Technology, School of Industrial and Systems Engineering, 1973.

3. Apple, James M., "The Systems Approach to Material Handling in Automation," Technical Paper MS 69-531, American Society for Tool and Manufacturing Engineers, 20501 Ford Road, Dearborn, Michigan 48128.

4. Bright, James R., Automation and Management, The Plimpton Press, Norwood, Massachusetts, 1958.

5. Bazaraa, Mokhtar Sadek, "The Determination of the Optimum Level of Mechanization in the Selection of Materials Handling Equipment," Master's Thesis, Georgia Institute of Technology, 1968.

6. Chiantella, N. A., "The Systems Approach to Plant Automation," A.S.T.M.E. - Vectors, Vol. III, No. 4, 1968.

7. Apple, James M., Plant Layout and Materials Handling, The Ronald Press Company, New York, 1963.

8. Apple, James M., Material Handling System Design, The Ronald Press Company, New York, 1972.

9. "Lagertechnik-Information," DEMAG Technical Brochure, N. V. Handels-en Ingenieursbureau W. B. van den Berg, Fruitweg, Postbus 1185, Den Haag, The Netherlands.

10. van der Meer, Anne F., "Ontwerp grondstoffen magazijn voor de Machinefabrieken van de N. V. Philips' Gloeilampenfabrieken," (Design for a raw materials warehouse for the machine factories of the N. V. Philips' Gloeilampenfabrieken), Master's Thesis, Technische Hogeschool Twente, Afdeling der Werktuigbouwkunde, Postbus 217, Enschede, The Netherlands, 1971.

11. Wilkie, George S., "Hands-off Warehousing System," Industrial Engineering, May 1973, Vol. 5, No. 5, pp. 12-19.

12. Pascual, Julio Jose, "An Approach to Automated Warehouses Analysis and Design," Master's Thesis, Georgia Institute of Technology, 1968.

13. Rivera, Lucas, "The Systems Approach to Warehouse Planning and Design," Master's Thesis, Georgia Institute of Technology, 1967.

14. Frazao, Romulo Martins Nascimento, "An Investigation of the Application of the Principles of Materials Handling as Criteria for Selecting Handling Equipment," Master's Thesis, Georgia Institute of Technology, 1971.

15. van der Meer, Anne F., "Phonodisc Long Term," Internal Report, Phonogram International b.v., Technical Efficiency and Organization, Baarn, The Netherlands, 1972.

16. Bolz, Harold A., Materials Handling Handbook, The Ronald Press Company, New York, 1958.